The JOURNAL
OF THE
FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA

DEVOTED TO SCIENCE AND THE MECHANIC ARTS

VOL. CLXVIII NOVEMBER, 1909 No. 5

MECHANICAL & ENGINEERING SECTION

(Stated Meeting held Thursday, March 25, 1909.)

POWER-HOUSE ECONOMICS IN BALTIMORE

BY
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DURING the summer of 1906 the service of the United Railways & Electric Company of Baltimore had become very much troubled by serious though temporary failures of the power supply. The main power station at Pratt street on the harbor had not been completed and the smaller steam operated stations scattered throughout the city were only adequate for small amounts of power; the substations fed from the central power station were not, at the time, equipped with sufficient machinery to supply the output called for without much overloading; the cables connecting the central power station with the substations were scarcely heavy enough to carry the rapidly increasing load, moreover the Company was continually adding to the service by replacing old and small cars with those of greater carrying capacity, which demanded a much greater amount of power.

The power station at Pratt street had been most seriously

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damaged by the great fire of February 19, 1904, so that but three of the old direct current units were available, and those for a short time only, as the city had decided to take the opportunity to widen Pratt street, for which purpose it appropriated about 60 feet off the front of the lot upon which this damaged house was situated. The new power house to replace that which was destroyed by fire had been designed within much shorter limits and so laid out as to accommodate three new 5000 k. w. reciprocating units, and the three old 1800 k. w. units still in operation in a temporary wooden shed on the old site on Pratt street.

At this time, September 1, 1906, arrangements were made with Mr. L. B. Stillwell of New York to assume entire charge of the power plants of the Company, not only for construction, reconstruction, and all necessary engineering changes, but for re-organization of the operating force and the complete operating of the plants from coal supply to trolley wire. As soon as practical a force was organized under the direction of the writer, and the problem of insuring the supply of power, as far as possible, during hurried additional construction was taken in hand.

The first requirement of the power plant of a street railway system is absolute continuity of operation; the next, that its operating cost shall be as low as compatible with continuity of supply, and last that the cost of construction shall not be excessive.

A study of the distribution system developed the fact that there were many points along the road that were very poorly supplied with current, for in addition to lack of power not enough copper had been installed during the period immediately preceding to keep up with the demand made by the additional and larger cars put into service. In fact, the whole situation was serious and demanded quick and heroic treatment. The late General Hood, then at the head of affairs, and Mr. W. K. House, at the time General Manager, together with the whole engineering force attacked the problem with vigor and enthusiasm.

The first thing demanded, as the holidays were fast approaching, was an increase of the alternating generator plant, for a reserve, and an addition to the cables connecting the generating plant with the substations. Arrangements had been

made sometime previously for an increase of plant in the one substation which was apparently much overloaded. Fortunately a practically finished turbogenerator of 5500 k. w. capacity was found which could be purchased and shipped in sixty days, although through an accident while testing, it was delayed more than a month, and contracts were immediately entered into for a foundation for this machine. New boilers were already under way on an old contract, and a new high tension cable, contract for which had been let the previous July, was hurried along and installed on Christmas Eve. Happily it was not needed.

With these arrangements completed, more time could be taken to study the general situation, and the layout for future demands as well as the immediate supply was given much consideration.

In the summer of 1906 the equipment of the United Railways Company consisted of nine power stations and five substations, as follows:

	Alternating Current. k.w.	Direct Current. k.w.
Pratt street		5,400
Pratt street	15,000	
Light street		2,000
Carey street		400
Gilmore street		500
Preston street		800
Falls Road		2,250
Back River		424
Bear Creek		675
Owings Mills		1,080
Total capacity	15,000	13,529

The five substations were as follows:

	k.w.
Druid Hill, capacity of rotaries	4,500
Northern or Harford Road	4,000
Eastern Avenue	3,000
Nunnery Lane or Arlington	1,500
Dugan's Wharf, temporary	3,000
Total capacity	16,000

Of the above mentioned stations, those at Bear Creek and Back River were only used in summer or in some emergency where the source of alternating current at Pratt street might be cut off for a time long enough to warrant starting them up. Bear Creek, was equipped with Climax boilers and a 375

k. w. Westinghouse Kodak machine; a 300 k. w. dynamo belted to a pair of engines of which the cylinders and frame had been very badly wrecked didn't count. The Back River plant consisted of plain return tubular boilers, with old-fashioned Thomson Houston dynamos belted to high speed engines.

The station at Owings Mills is so far from the city as to put it out of consideration in any central source of supply of current except it might in time be furnished from the line from McCall Ferry. It is equipped with return tubular boilers, one Rice and Sargeant engine, direct connected to a 330 k. w. dynamo, and three high-speed engines belted to three 150 k. w. dynamos. The engines all run condensing.

Of the others, Light street station is equipped with water tube boilers, Corliss type of non-condensing engines and 500 k. w. belted dynamos. If it had been possible to get condensing water for this plant, its economy could have been scarcely excelled, as the engines were of good type and the operating force competent though small.

Carey street had Climax boilers, and high speed engines with small belted dynamos.

Preston street was equipped with water tube boilers and a good type of compound non-condensing moderate speed engines with belted generators of quite an old type, which could never be made to give voltage exceeding 550.

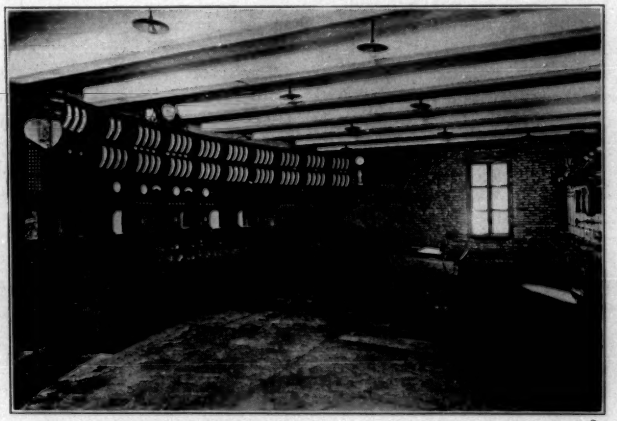
Gilmore street was equipped with return tubular boilers and high speed engines of the Armington Sims make of quite the oldest type, and belted generators of comparatively small capacity.

Falls Road station had Corliss type, vertical, and Climax boilers; Corliss type of compound condensing engines belted to comparatively large generators. There were also two Westinghouse Kodaks in an addition at one end of the building. This station was quite well equipped, well located to take its proper load, and being well supplied with condensing water should have been quite efficient. But it was woefully uneconomical in operation, and could never be run at anything like its full capacity owing to the inability of the generators to commutate the current when loaded.

The central power station at Pratt street is located at the land end of a long pier which extends a long way into the

harbor. Water for condensing purposes is taken in on the west side and discharged into the dock on the east side of the pier. Coal is unloaded from barges directly into the storage bins in the top of the boiler house.

This station was equipped with five 2,000 k. w. direct connected generators on vertical compound condensing engines of quite the latest type; one 5,000 k. w. generator direct coupled to a double vertical-horizontal compound condensing engine and three 1800 k. w. D. C. dynamos direct connected to vertical com-



Pratt Street power station. A. C. control switch-board.

pound condensing engines. There were twenty boilers of 480 h. p. each, and more were being added at the time, as steaming capacity was badly lacking.

As to the substations, while the total nominal capacity of 16,000 k. w. was 1,000 k. w. more than that of the generating station, there was no reserve at either point, and before additional supply could be installed, the generators of 15,000 k. w. capacity were often called upon for 18,000 to 20,000 k. w., while the Druid Hill and Hartford Road substations were putting out at times very heavy overloads and needed relief as soon as it

could be furnished, in fact a 1,500 k. w. rotary had already been ordered for the Druid Hill substation.

The substation on Dugan's Wharf immediately in the rear of the Pratt street power house, had been put there temporarily, following the fire, and would be dismantled just as soon as other provision could be made to supply its output.

A complete study of the situation developed the fact that with the construction of one new substation located near the center of the city, the increase in the size of the substation at Hartford Road, the readjustment of the copper to meet these changes, and the addition of the conductors necessary for putting the direct current distribution into proper condition, the temporary substation at Dugan's Wharf could be abandoned, the steam station at Light street could be shut down, all the smaller steam stations could be put out of service and the whole supply of power would then be developed at a higher efficiency at the central power house at Pratt street.

The supply of power at the Bay Shore resort still remained in question and the great increase of traffic expected during the following summer called for a supply which should be positive and continuous.

One of the most serious problems was the design and location of a switchboard which would not only take care of the output of the machinery then in use, and that to be immediately added, but would handle the power supply for a long time in the future. Tentative plans were made showing possible additions to the plant that could be located on the remainder of the Pratt street lot owned by the Company, and it was found that an additional capacity of 40,000 kilowatts could be made. The switching gear and structure were, therefore, so designed as to be easily enlarged to care for this increase. During the planning a contract was entered into with the McCall Ferry Power Company for a supply of 10,000 k. w. of current from that source, and the switchboard had still further to be arranged for the accommodation of this power. As power interchange with the Consolidated Gas, Electric Light, Heat & Power Company must be kept always available, room for this was also made. This required a switchboard which would control current from one station in sight; two out of sight and at some distance; water power thirty-five or forty

miles away, and a power house located two or three miles off. The switchboard has been designed so that if carried out to its ultimate limit it will be capable of controlling about 120,000 k. w.

The duct problem then developed an acute stage, for it was with some difficulty that room could be found on the narrow wharves left on either side of the power house to accommodate all those needed to carry all the cables made necessary by the requirements above mentioned. The situation was much relieved, however, by changing the original plans of placing the three 1,800 k. w. D. C. units along the north wall of the newly constructed engine room of the Pratt street power station, and building at this location the switching structure. In addition to this a large vault was constructed in Pratt street under the sidewalk along the front of the building, into which all cables entering from the ducts on the street are taken for distribution to their proper places. A more detailed description of this structure will be given later.

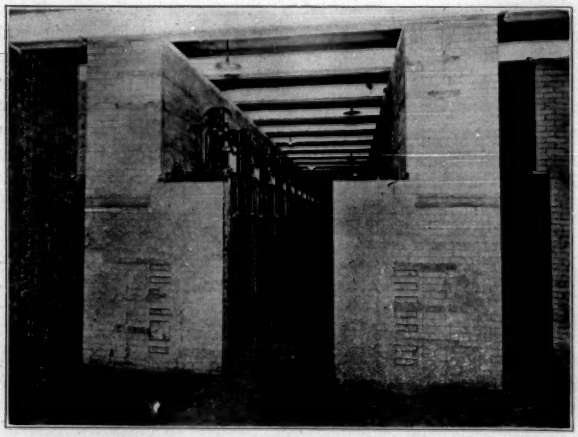
DIRECT CURRENT SWITCHBOARD.

Means had to be supplied also for handling the D. C. output from the three 1800 k. w. dynamos, and again for distributing the current from this source to a large number of outgoing feeders. This was all very satisfactorily accomplished by suspending a light steel structure from the inside of the east wall of the main power house, about 20 feet above the floor, and placing upon it the necessary switch panels and instruments. The cables for both machines and feeders are run up back of this structure through ducts built up against the wall, and held thereto by a light framework of steel and expanded metal, the whole being plastered over to a smooth surface.

FOUNDATIONS.

As considerable trouble had been experienced with a foundation for a large reciprocating engine which had been installed previous to our taking up the work, much attention was given to this subject as it came up. The whole surface upon which the new Pratt street power station was built had been occupied by the one that was burned. This site had been piled all over

its area by piles about four feet apart, the stringer pieces 12 x 12 had been bolted on top, two layers of planking, each four inches thick were placed over these stringer pieces, and the whole was overlaid by a foot of brick laid in cement. As the shaking of the foundation mentioned indicated that extra piling would be necessary in constructing additional foundations for the turbo-generator, for an additional 5,000 k. w. reciprocating unit, and for the two 1,800 k. w. D. C. units which it was decided to place along the center of the room; the top covering of brick,



Pratt Street power station. Alternator oil switch gallery.

plank and stringers was first removed; then the mud and silt were excavated for a depth of five feet around the existing piles and intermediate piles were driven between all the rows of those already in place. In addition two rows of sway piles were driven around the outer edge of each foundation, then concrete was filled in about the heads of all these piles, and over their tops, and upon this the superstructure of the foundation was constructed of reinforced concrete. In every case tie rods of steel, and keystones were left in the concrete, to which the adjacent foundation was tied. All these foundations were as

stiff as could be desired, and no swaying of any kind has taken place since they were built.

The swaying of the first foundation constructed previous to our contract, having become dangerous through breaking of the steel rods with which it was tied to another foundation across the room, means were taken to stiffen this up and tie it to the newer and more solid structures. Temporarily rails were used for surrounding this foundation and tying it to the mate, which had been more recently constructed. This held it as steadily as could be desired. The space in front was then excavated to the silt which was in turn excavated to a depth of several feet as had been the rest. Piles were then driven between the other piles, but in this case all were driven as sway piles, half leaning in one direction away from the shaking structure, the other half leaning in the opposite direction. All the mud and silt was excavated about the foundation itself, and the frame of structural steel which had been used to tie this to the opposite foundation was strengthened and used with rods to still tie it to the same structure. Other frames of structural steel were built in between this foundation and its mate; all the tie rods which had been left in the later built foundations were tied in, then the whole was covered in with concrete all around to the depth of five or six feet up to the level of the new basement floor. Not the slightest vibration is now noticeable in this foundation, and the one opposite upon which is placed one of the 1,800 k. w. D. C. units has also been stiffened by the changes, so that it also is now free from vibration.

DOCKS.

As the city was about to commence the reconstruction of the pier walls along the wharves upon which the new Pratt street power station is located, and as some trouble had been experienced from the methods of construction which had been in use, it was felt that excavating for any such form of construction would be dangerous to the stability of the power house, and, therefore, considerable time and study were given to methods of construction which would obviate these dangers while meeting all the requirements. A design was finally adopted by the harbor engineer, Mr. Lackey, which it is thought will not only serve much better as a pier, but will permit the

construction of electrical conduits, and the laying of water pipes and sewers along the wharves without offering serious obstruction.

REMOVAL OF 1,800 K. W. D. C. GENERATORS.

The removal of 1,800 k. w. D. C. generators from the street to their permanent positions entailed much thought and labor, as the supply of current which they represented could not for a minute be spared. As additional alternating supply in the shape of the 5,500 k. w. turbo-generator was available, one of the newly ordered 1,500 k. w. rotaries was hurried along and installed in the temporary Dugan's wharf substation, in the rear of the central power house. This furnished a supply of current quite equal to the output of one of the 1,800 k. w. D. C. generators, so that as soon as one was moved and connected up another could be shut down and dismantled. The installation of this extra 1,500 k. w. rotary was of great assistance all through the period of upbuilding of the plant as it was always ready in case of trouble with any of the D. C. machines, and was only removed to its permanent location in the central substation, on Lombard street after all other machinery had been in working order for some time.

CENTRAL SUBSTATION, LOMBARD NEAR PENN STREET.

The location of a station at this point was dictated by several conditions:

1. The overloaded condition of the Druid Hill Avenue substation, together with the fast growth of its load.

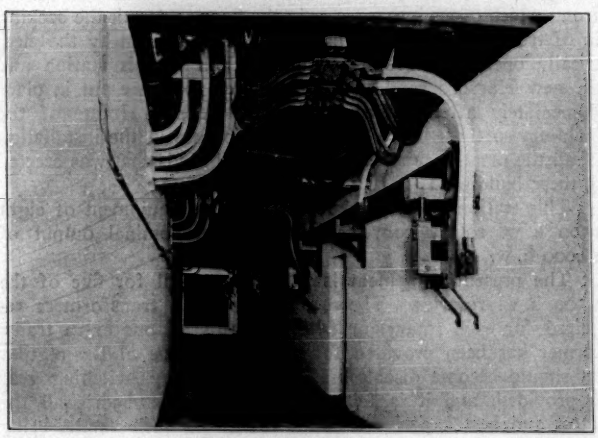
2. The length of feeders from that station, which gave relatively poor service at or near their ends.

3. The great desirability of closing the Light street steam-power station at an early date, owing to its lack of economy and the impossibility of bettering that economy, as no condensing water was available.

4. The relief of the direct current load on the central power plant at Pratt street, so that the temporary substation at Dugan's wharf might be closed.

In addition to providing a much superior supply, the closing of the two stations above mentioned was expected to result in an annual saving of at least $35,000 in cost of operation.

Knowing the conditions of operation of the cars, and the load called for by each line, it is a simple mathematical problem to determine the best location of a power supply centre, but the actual location must of course be governed by availability of reasonably inexpensive real estate, and of surroundings that will not be materially damaged by the location of such a supply station nearby. The actual mathematically correct location of this station for the existing requirements was found to be just west of Paca street on Lombard, and search was made for



Central substation, basement.

available real estate in that immediate neighborhood, without success. As requirements change year by year, it is not necessary to stick to the exact centre of load, mathematically determined, so that real estate officials were given some leeway as to location, resulting in the final purchase of the ground upon which this new station is now located on Lombard street, just west of Penn street. The lot is 154 feet deep from Lombard street to Cider alley, and 55 feet wide from house line to house line, but the building has been constructed only 48 feet wide in order to have a clear space all around for five protection, and to avoid any possible trouble, due to vibration of machinery.

The building is of substantial brick construction on a steel frame, and has a concrete roof on steel girders; also concrete foundations and basement floor. All windows and doors have metal frames and covering, and the building is amply lighted by numerous windows in both ends and a large glass-roofed monitor running nearly the whole length of the building. The front is of attractive appearance, though of simple design in brick with light stone trimmings and a metal cornice. There is a small door at the rear opening into Cedar alley, but the main entrance is through a large door at the westerly end of the front, which opens into a recess in the floor to permit the backing in of trucks, from which machinery can be taken by the electrically operated travelling cranes. Both in this station and the new Harford road substation the cranes were put in place immediately after the completion of the steel frame of the building, so that they were available for use in the installation of all the machinery and apparatus of all kinds that was erected in these buildings.

This station is designed for an eventual equipment of eight 1500 k. w. rotary converters, or a total nominal output of 12,000 k. w.

The present equipment is being completed for five of the 1,500 k. w. rotaries. There are three static transformers required for each rotary, or fifteen in all, and one extra transformer has been provided for use in case one of the regular lot should become disabled. All the necessary switching gear is provided, and it is felt that this station embodies all the latest and best experience in the design of such plants, being simple in design of all connections, and location of all switching gear and apparatus, so as to insure the smallest possible risk from fire, the least risk to life, and surest continuity of service together with ease of handling and control of the apparatus in service, as well as low cost of operative labor required. A goodly sized storage battery is installed and used to operate the switches in case the outside current is cut off for any cause, and further, for supplying light for the station at such times as the supply from this regular source may be stopped. The station is wired for lighting in pipe in the latest approved manner, and light for the main operating room is supplied from a number of Cooper-Hewitt mercury vapor lamps, affording a very effi-

cient and economical service. Two arc lamps are also suspended just below the monitor, and are so arranged as to be automatically thrown on the storage battery in case the regular lighting fails from any cause. The basement is lighted by incandescent lamps. Suitable toilet rooms are provided at the front end of the basement and metal lockers are furnished for the clothing of the operatives.

The City Electrical Commission which lays all electrical conduits in Baltimore constructed conduits and manholes leading to and from the building to conform to the plans of the station. The supply feeders bringing alternating current from Pratt street power station at a pressure of 13,000 volts, enter the front of the basement at the easterly side, and are conveyed through vitrified tile conduits under the floor to their various locations along that side of the building, and are connected through oil switches to the copper busbars, which are located in a brick structure laid up along the easterly wall of the basement. These busbars are there connected to the static transformers through other oil switches and allied devices. The outgoing direct current cables for distributing the working supply of current to the trolley lines, leave the building by front and rear through a line of ducts in the basement laid along the westerly wall of the same. For the present, and until the city duct system is extended, there will be some ten feeders (cables) leaving the station through the wall immediately in the rear of the distributing or direct current switchboard, and connecting with the overhead lines on the north side of Lombard street. The line to Curtis Bay is so long that the regular pressure of 575 volts at the station will not be sufficient at time of full load, so a large "booster" has been installed in one corner of the main floor.

All the studies indicate that this station will afford much relief to the whole power situation in the centre of the city, and, as mentioned, save a very considerable amount in the cost of power.

NORTHERN, OR HARFORD ROAD, SUBSTATION NO. 2.

Studies of the conditions at the existing Northern substation showed it to be overloaded, and the load on it fast increasing. All calculations indicated that the best results as to

supply and economy of the same would be obtained by enlarging this station, rather than by starting another at some other centre, there being a considerable surplus of feeder copper already connected to the station.

Arrangements were therefore made for duplicating the existing building as to size and external appearance, although keeping it separate in every respect; and to equip it with units of somewhat larger capacity; also to re-arrange the control of both stations in a somewhat improved manner.

Northern substation, No. 2.

The building is of brick, on a steel frame, with concrete basement floor and building foundations, and concrete foundations for the rotaries. This building is designed to receive an equipment of four 1,500 k. w. rotaries, with all necessary transformers, switching gear, &c., but two only are installed at present. The control of the switching gear is for convenience located in the original station, in connection with the control and switching apparatus of that plant. This insures the lowest cost of operation and, as the new apparatus is for use in conjunction with the old, makes decidedly the best arrangement from an operating standpoint. This new station is entirely

separate and distinct from the old, the wall of the old station not even being used as a "party wall," except as a parapet above the roof. The only connection between the two is that of the cables carrying the direct current from the rotaries to the distributing switchboard in the old house, and the small control cables and connections from the switching gear, located in the new house, to the control panels which are, for convenience of operation, located with the others in the original station. The equipment and general design is quite similar to that of the central substation, with such variations as were necessary for carrying the direct current output of the rotaries through the old house.

The new house is equipped with an overhead, electrically operated travelling crane of twenty tons capacity. It happened that the two new rotaries were almost ready for operation at the time of the destruction of the Falls Road power house by fire on the night of October 5, 1907, and, by a little hurried work, these machines were made ready and connected to the line in time to provide a fairly good service for the lines deprived of power.

BAY SHORE POWER STATION.

Bay Shore is an amusement park located upon the shore of Chesapeake Bay, some fifteen miles from the center of Baltimore City, and twelve miles away from the nearest substation, that at Eastern avenue. During the first season that the park was opened—that of 1906, beginning some time in August—it was supplied with power for operating the cars through a number of low tension cables operated from the substation at Eastern avenue. Lighting was also supplied from the same source through two three-phase circuits running on the telephone lines over another route to the park. The power was found to be quite inadequate as installed, the lighting very poor and uncertain and for both these reasons it was felt that it was necessary to provide an absolutely continuous supply for the approaching season of 1907, and the studies indicated that all the conditions could be best met by the establishment of a power plant closely adjacent to the park itself. The main consideration leading to this decision being the prevalence of lightning during the summer storms, to which the long overhead

line between the Eastern avenue substation and the Park, was fully exposed. The lighting and power for the park as supplied from Eastern avenue was several times affected and the lights and power shut off during an evening's entertainment. The price of copper for the season of 1907 also added further argument to strengthen the opinion in favor of the local power station, as it was estimated that the cost of copper to obtain the same results would be several thousand dollars more than a whole new power station, and would then be subject to the dangers from lightning, above mentioned. Deliveries of elec-

Bay Shore power station.

trical apparatus were so backward in the spring of 1907 that it would have been simply impossible to have had this station in readiness for the season, and advantage was taken of the fact that the Company already had considerable good steam and electrical apparatus in stations that was not in use, and high class units were selected from this unused machinery and a station was designed for their reception. It was not considered practicable to locate this station close to the Park, owing to the smoke from its chimnies, and the first location selected was close to the shore of the bay, along the return railway track, but the owner of the property refused the use of this

point, as he desired it for residential purposes, and insisted that the station be located at least five hundred feet back from the shore, which was eventually done—along the curve of the return track. A little over an acre of ground was purchased, so shaped as to accommodate the spur tracks for coal trestle and station use, and the building is so located upon this land as to permit of further extension at any time should future growth demand it.

After excavating to a sufficient depth, piles were driven to furnish a firm foundation for buildings and machinery, and a reinforced concrete building of plain but substantial and fireproof design was constructed. There is nothing whatever in this building to burn but the window sash, frame and doors, and if they were entirely destroyed that would be practically all the damage possible. Even the destruction by fire of the wooden bulkhead, which is used for closing the rear of the boiler room in winter could do no further damage. This station is equipped with two 600 H. P. Morin Climax boilers, two 300 H. P. boilers of same make, one Westinghouse Kodak generator and engine of 375 k. w. capacity, one Kodak generator—same make —200 k. w. capacity, for supplying 500-volt direct current to the Park for miscellaneous power purposes, and four Thomson-Houston 200 k. w. 550-volt generators driven by belt from four tandem compound McIntosh & Seymour engines; these generators being used in connection with the 375 k. w. Kodak unit, for supplying current for the local section of the railway for a distance of about three miles back. The steam piping and feed water system, which by the way is taken from a couple of driven wells on the property, one of 400 feet and the other of 600 feet—is all so designed as to provide against the least chance of shut-down from trouble in that direction, and in fact the whole design of the station has been made with a view to absolute continuity of operation.

There is also installed in this section a new 250 k. w. 3-phase alternating current generator for supplying the lighting at the Park in connection with the supply from the Eastern avenue substation. This generator can be used alone or in connection with a line from the Eastern avenue substation, or can be held in reserve for use in case of trouble on that line. In order to still further insure continuity of this lighting supply,

a small fireproof building of reinforced concrete was erected at the Park, and the three 75 k. w. transformers through which the transmitted current of 3,300 volts is reduced to 110 volts for the Park lighting, were removed to it from a temporary wooden shed. The apparatus for this station was increased by one 75 k. w. transformer, a duplicate of the other three, and this has been so installed as to permit its connection to replace any one of the three that should for any cause be damaged. A 40 H. P. motor generator is also installed in this building for supplying 110 volt direct current to various small appliances about the Park. This power station at Bay Shore was constructed under numerous difficulties, the machinery being installed as soon as the foundations were ready for its reception, and without waiting for the building, so that by the time the roof was in place practically all the machinery had been in service supplying current for the season.

DRUID HILL SUBSTATION.

The equipment of this station was increased by the addition of a 1,500 k. w. rotary converter and its transformers, but a 500 k. w. machine was removed from this house to the substation at Nunnery Lane, which is completed and rounded out by the addition.

Two additional high tension cables were added to the two existing cables connecting the substation with the Pratt street power house.

The busbar pit for high tension connection was much enlarged and some of the low capacity switchboard panels on the D. C. feeder side were replaced with others of much increased capacity taken from the temporary substation on Dugan's Wharf. This station has been much relieved since the new central substation on Lombard street was put in full operation.

EASTERN SUBSTATION.

This station was originally designed to accommodate six rotaries of 1,000 k. w. each. Only three machines were in place up to the Spring of 1908, when the three 1,000 k. w. rotaries at Dugan's Wharf were transferred to this station and the switching structure and control panels were re-arranged to care for their output.

RESULTS.

Owing to the chaotic condition of the power equipment in the summer of 1906, including not only that at Pratt street, which was undergoing many changes, but to the outside smaller steam operated plants as well, the whole operating forces needed not only weeding out but reorganizing and this was taken in hand vigorously.

The Pratt street force in December, 1906, consisted of 154 operators; this was gradually reduced during the year until in December, 1907, there were 121, while the output had increased by more than 750,000 kilowatt hours. As Pratt street took on more power, the outside plants were closed, thus doing away with much labor.

Many other economies were introduced and much attention was paid to the coal consumption, that being by far the largest item of expense connected with the plant.

CO_2 apparatus was installed to assist in the training of firemen, and one boiler was fully equipped for testing and many trials were made in order to determine the best conditions of load under which to operate, and the conditions giving the lowest consumption of fuel.

In January, 1907, the coal consumption per kilowatt hour for all stations was 4.4 pounds, while for December of the same year it had fallen to 3.2 pounds.

At the Pratt street station the coal consumption for the month of January, 1907, was quite abnormal, being 4.3 pounds per kilowatt hour, while in December of the same year it had decreased to 3.15 pounds and during the months of July and August it was 2.95 and 2.9 pounds, respectively. This consumption of coal fell to 2.8 pounds per kilowatt hour in August, 1908. This was owing to the fact that nearly all the smaller outside plants had been shut down, thus throwing the large part of the load on Pratt street station.

The kilowatt-hour output of the Pratt street station as compared with all station changed as follows:

	Pratt St.	All stations	Per cent. on Pratt St.
1905	56,266,576	70,031,906	80.0
1906	70,932,528	87,946,479	80.8
1907	87,543,846	100,665,951	87.5
1908	92,412,742	99,345,544	93.0

The consumption of coal per kilowatt hour for the several years is shown in the following table:

	Coal in pounds per kilowatt hour	
	Pratt St.	All stations
1905	3.63	3.87
1906	3.55	3.81
1907	3.25	3.48
1908	3.09	3.28

The cost per kilowatt hour for all stations decreased during the year 1907 to 8 per cent. below that of 1906; while for the year 1908 this cost had fallen some 23 per cent. below that of 1906.

Owing to the fact that all the power can never be supplied from Pratt street station solely, the cost per unit for the whole output will always be somewhat higher than that for those stations of large size supplying all the power that is used. However this cost will compare very favorably with any of the other large plants in the country which are equipped with reciprocating engines.

The power plants and equipment of the United Railways & Electric Company are now as follows:

	k.w.
Pratt street, alternating current	25,500
Pratt street, direct current	5,400
Bay Shore, alternating current for lighting	250
Bay Shore, direct current	1,375
Owings Mills, direct current	1,080
Light street, direct current, reserve	2,000
Falls Road, direct current, reserve	750
Total A. C.	25,750
Total D. C., generators	10,600

Substations equipped as follows:

	k.w.
Druid Hill	5,500
Northern or Harford Road	7,000
Eastern Avenue	4,000
Nunnery Lane or Arlington	2,000
Central substation	7,500
Total	26,000

As the power equipment now stands, there is one unit in reserve in the Pratt street power house and in each of the substations.

In closing, I can do no better than to quote from an

editorial which appeared in the Street Railway Journal last Spring:

The writer says: "There is no task that gives a finer scope for engineering skill than the reconstruction and modernizing of an important plant in full operation. Any kind of mediocre talent enables a man to sit down with a bunch of manufacturers' catalogues and the blue prints of a few of their latest creations, and lay out a station that will be gleefully described as "following standard practice." This bears the same relation to engineering that stencil work does to art. To take a big system and keep it running, while its power equipment is being turned inside out, and to renovate it without needless cost, is a task of a very different order."

EFFECT OF OXYGEN IN COAL.

RECENT investigations by the United States Geological Survey have shown that oxygen, so essential to all life, forms in coal an impurity that is almost as injurious as the ash content. The subject is, of course, of great importance to the consumer, whether he be a manufacturer using hundreds of tons or a householder who has to supply only a furnace.

David White, an account of whose investigations on the subject has recently been published by the Geological Survey as Bulletin 382, was led to these conclusions in the course of work undertken in an attempt to devise an acceptable classification of the many different sorts of coals. He states that oxygen and ash are of very nearly equal negative value, ash being probably a little more injurious in most coals; and that the calorific value of coals in general is indicated by the balance between the total carbon on the one hand and the sum of the two great impurities, oxygen and ash, on the other. The practical application of these statements appears in considering the effect of the exposure of coal to the weather. The weathering of the lower grades, especially lignites, bituminous coals, and peats, is marked by the accession of oxygen, which is taken into combination. This increase of the oxygen content permits a calorific deficiency, which, on account of the high anticalorific value of oxygen, is often serious. It is possible that in many cases considerable increase of oxygen and consequent loss of efficiency are suffered by the lower-class fuels between removal from the bed and consumption; and it is probable that in the subbituminous coals, and more especially in the lignites, oxygenation begins immediately after the coal is blasted from the face in the mine.

A comparison of the calorific values of the car and mine samples seems to warrant the apprehension that in some cases at least considerable deterioration occurs. The amount of loss depends not only on the kind of coal, but also on the conditions of loading, the kind of car, the size of the fragments, the weather, and the period of transit, which for many coals is over three weeks.

THE THEORY OF IMPACT AND ITS APPLICATION TO TESTING MATERIALS.

BY

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(Concluded from October, page 259.)

DERIVATION OF EQUATIONS.

Consider now the equations for the time-deflection curve, on the assumption of inelastic or dead impact. Dr. A. Gessner, in a 38-page pamphlet entitled "Upon the Straining of Freely Lying Bodies Through Impact," [3] has developed theoretically the formulæ for the time-deflection curve for beams supported at the ends and struck at the centre, and compared the theoretical values thus obtained with the actual results of his experiments upon cast-iron. His actual curves were obtained by tracings made by a falling weight upon a revolving drum, in a manner fully described in his article. His work is fundamental, and therefore his theoretical development will be given here, as follows:

Let us call the transposed mass of the beam m_o. Then the velocity after striking is

$$c = \left(\frac{A}{A + m_o}\right) v_o \qquad (21)$$

For brevity call $A + m_o = M$.

Call the weight of the hammer Q whose mass is A.

Call the weight of the beam G whose mass is D.

At any point of deflection of the beam where y is the amount of deflection, and K is the amount of work done in producing this deflection, and v is the velocity at this point, the following relations hold:

$$\left.\begin{aligned} \tfrac{1}{2}Mc^2 + Qy &= K + \tfrac{1}{2}Mv^2 \\ K &= \tfrac{1}{2}M(c^2 - v^2) + Qy \end{aligned}\right\} \qquad (22)$$

and for the instant of greatest deflection

$$K_1 = \tfrac{1}{2}Mc^2 + Qy_1 \qquad \text{since } v = o \qquad (23)$$

[3] "Uber die Beanspruchung Freiaufliegender Träger durch Stoss." Wien, 1906.

All this reasoning is on the supposition that the elastic limit is not exceeded and that Hook's law holds.

From the static relations

$$K_1 = \frac{24EJ}{l^3} y^2$$

Call

$$\frac{48EJ}{l^3} = S$$

a constant. Then

$$K_1 = \frac{S}{2} y^2 \tag{24}$$

The greatest bending under static load Q is

$$\delta = \frac{Ql^3}{48EJ} = \frac{Q}{S} \tag{25}$$

Therefore

$$\tfrac{1}{2}Mv^2 - \tfrac{1}{2}Mc^2 = S\delta y - \frac{S}{2}y^2, \text{ from } (22).$$

Differentiating,

$$Mvdv = (S\delta - Sy)dy \tag{26}$$

But acceleration is

$$\frac{d^2y}{dt^2} = v\frac{dv}{dy}$$

Substituting the values from (26),

$$M\frac{d^2y}{dt^2} = S\delta - Sy$$

whence

$$\frac{d^2y}{dt^2} + \frac{S}{M}y - \frac{S}{M}\delta = o. \tag{27}$$

Integrating this equation,

$$y = C_1 \sin\left(t\sqrt{\frac{S}{M}}\right) + C_2 \cos\left(t\sqrt{\frac{S}{M}}\right) + \delta.$$

But for $t = o$, $y = o$, and at the same time $v = c$.

Therefore

$$o = C_2 + \delta, \; C_2 = -\delta$$

$$\frac{dy}{dt} = v = C_1\sqrt{\frac{S}{M}} \cos\left(t\sqrt{\frac{S}{M}}\right) + \delta\sqrt{\frac{S}{M}} \sin\left(t\sqrt{\frac{S}{M}}\right)$$

For $t = o$, $v = c$.
Whence

$$c = C_1\sqrt{\frac{S}{M}},\ C_1 = c\sqrt{\frac{M}{S}}$$

Hereby we can express y as a function of time t,

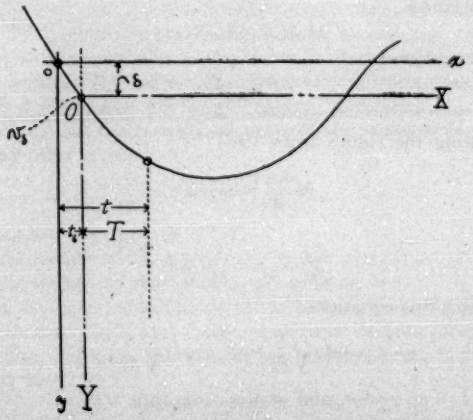
$$y = c\sqrt{\frac{M}{S}}\sin\left(t\sqrt{\frac{S}{M}}\right) + \delta\left(1 - \cos\left(t\sqrt{\frac{S}{M}}\right)\right) \qquad (28)$$

$$\frac{dy}{dt} = v = c\cos\left(t\sqrt{\frac{S}{M}}\right) + \delta\left\{\sqrt{\frac{S}{M}}\sin\left(t\sqrt{\frac{S}{M}}\right)\right\} \qquad (29)$$

$$\frac{d^2y}{dt^2} = a = -c\sqrt{\frac{S}{M}}\sin\left(t\sqrt{\frac{S}{M}}\right) + \delta\frac{S}{M}\cos\left(t\sqrt{\frac{S}{M}}\right) \qquad (30)$$

Equation (28) when plotted gives the curve deflection and time, using o deflection and instant of contact as the origin of coördinates, for the beam horizontal and the hammer falling vertically.

FIG. 7.



These equations will be in better form, however, if referred to the axes XY, whose origin is at the deflection y^s which would be produced by a static load Q. In order to obtain this transformation it is only necessary to make the substitutions,

for $t = T + t_s$
for $y = Y + y_s$

From equation (28)

$$o = c\sqrt{\frac{M}{S}} \sin\left(t_s\sqrt{\frac{S}{M}}\right) - \delta\cos\left(t_s\sqrt{\frac{S}{M}}\right)$$

Whence

$$t_s = \sqrt{\frac{M}{S}} \text{ arc tan}\left(\frac{\delta}{c}\sqrt{\frac{S}{M}}\right) \tag{31}$$

And from (29)

$$v_s = c\cos\left(t_s\sqrt{\frac{S}{M}}\right) + \delta\sqrt{\frac{S}{M}}\sin\left(t_s\sqrt{\frac{S}{M}}\right) \tag{32}$$

The resulting equation after making the substitutions and reducing is

$$Y = v_s\sqrt{\frac{M}{S}}\sin\left(T\sqrt{\frac{S}{M}}\right) \tag{33}$$

Y_1 is maximum for

$$\sqrt{\frac{S}{M}}\,T_1 = 1$$

$$Y_1 = v_s\sqrt{\frac{M}{S}} \tag{34}$$

$$T_1 = \frac{\pi}{2}\sqrt{\frac{M}{S}} \tag{35}$$

To eliminate the value of v^s, equation (23) may be written,

$$K_1 = \frac{S}{2}y_1^2 = \frac{Mc^2}{2} + S\delta y_1$$

Whence

$$y_1 = \delta + \sqrt{\delta^2 + \frac{Mc^2}{S}}$$

and since

$$y_1 = \delta + Y_1$$

$$Y_1 = \sqrt{\delta^2 + \frac{Mc^2}{S}} = \frac{1}{S}\sqrt{Q^2 + Mc^2S} \tag{36}$$

Substituting values for M, c, and S,

$$Y_1 = \frac{Ql^3}{48EJ}\sqrt{1 + \frac{96EJ}{l^3} \times \frac{(Q + \frac{G}{2})}{(Q + \frac{5}{8}G)^2} \times H} \tag{37}$$

The value for the transposed mass of the beam m_o is here taken as ½ the mass of the beam for kinetic energy, as being near enough to 17/35, and as ⅝ the mass for momentum in finding the value for c. According to our reasoning on page 252 (Jour. No. 1006), the value 17/35 should be used in both cases, which would reduce the equation to

$$Y_1 = \frac{Ql^3}{48EJ}\sqrt{1+\frac{96EJ}{l^3}\times\frac{H}{(Q+\frac{17}{35}G)}}$$

or

$$\frac{Ql^3}{48EJ}\sqrt{1+\frac{48EJ}{(Q+\frac{17}{35}G)l^3}\times 2H} \qquad (38)$$

It should be remarked that the ordinate $O - X$ is obtainable experimentally with greatest ease. All that is necessary is to rest the hammer on the specimen and turn the drum with the dead load of the hammer on the specimen. The other ordinate—ox—is not easy to obtain with accuracy.

From (15) the time of one semivibration is evidently

$$\pi\sqrt{\frac{M}{S}} = \pi\sqrt{\frac{Q+\frac{17}{35}G}{g}\times\frac{l^3}{48EJ}} \qquad (39)$$

which is independent of velocity or height of fall. This is true only provided the hammer and beam remain together as one piece. This agrees with the deductions of other authors (see Merriman's Mechanics of Materials, page 253). If the weight separate from the beam, after rebound, the time of one semivibration becomes:

$$\pi\sqrt{\frac{17G}{35g}\times\frac{l^3}{48EJ}} \qquad (40)$$

It will be seen that this expression for semivibration is in the same form as that for a simple pendulum, which is

$$\pi\sqrt{\frac{l}{g}}$$

l being the length. In other words it would vibrate in the same time as a pendulum whose length is

$$\frac{(Q+\frac{17}{35}G)}{S} = \frac{(Q+\frac{17}{35}G)l^3}{48EJ}$$

The stress on the extreme fibre at the maximum deflection is, from the static relations, for beams of symmetrical cross section:

$$P = \frac{6Ey_1h}{l^2} = \frac{6Eh}{l^2}(\delta + Y_1) = \left(\frac{Ql^3}{48EJ} + Y_1\right)\frac{6Eh}{l^2}$$

$$= \frac{Qlh}{8J}\left(1 + \sqrt{1 + \frac{48EJ}{(Q + \frac{1}{35}G)l^3} \times 2H}\right) \qquad (41)$$

Where h is the depth of the beam.

It should be noted in this case where the hammer falls vertically, that the time of actual contact is greater than the time of semivibration by the amount $2t_\delta$, or time of contact =

$$2t_\delta + \pi\sqrt{\frac{M}{S}}$$

t_δ is given by equation 31, page 339. In horizontal impact the time of contact is evidently the same as that of the semivibration.

By a very careful comparison with the curves obtained from his experiments on cast-iron beams, Dr. Gessner finds them to be practically identical to the curves given by these theoretical equations. He therefore draws the following conclusions regarding cast-iron, when the ratio of $\frac{c}{\varrho}$ is less than $\frac{1}{4}$, heights of fall of 1.5 to 5 centimetres. His spans were 50 centimetres and heights of section about 2 centimetres. The beams for rupture were broken by a single blow.

1. That the assumption of inelastic impact is generally correct. The curves show very plainly a sharp change at the instant of impact. Elastic deformations show themselves by vibrations of the hammer causing the tracing to be wavy. It is difficult to correctly limit the application of the above formulæ.

2. The assumption that the form of the curve of the axis of the beam is the same under impact as under static loading is also practically correct.

3. The assumption that within the elastic limit Hook's law applies in impact as well as static loading holds good.

4. The loss of energy to the anvil due to vibrations is a very important consideration in impact tests, especially in compression tests. In beams with proper span probably none of the pressure of the first instant during which the local deformation occurs reaches to the supports, as the time is too brief. The pressures on supports during the further bending probably vary directly with that on the point of contact, and when no abnormal relations exist, give rise to practically no loss of energy.

With reference to the special case of his tests upon cast-iron beams Dr. Gessner draws the following final conclusions:

1. The values for the breaking work as likewise those for the total deflection in bending, which are obtained by static and dynamic tests of the material, differ but little from each other.

2. Since the specimens of cast-iron experimented upon were of fairly high grade it is not impossible that for poorer quality as likewise also for hardened pieces, the impact tests might give smaller values than the static tests.

3. That characteristics of material shown in static tests are also shown with the same degree of clearness in the impact tests. This establishes the principle that impact tests are very well adapted for the determination of the quality of the material.

4. The remaining energy in the weight after breaking the beam should not exceed 30 per cent. of its initial energy, and the weight of the hammer should be at least four times the weight of the specimen.

Before undertaking the experiments the same author made a study of previous experiments and briefly sums up the main points as follows:

1. The surest means of obtaining indisputable figures lies in the exact measurement of the breaking-work, that is, that energy which is needful to break the stick in one blow.

2. The amount of bending or total deflection of the specimen at break is likewise an indication of the quality of the material.

3. Both these quantities are rightly measured only when the expended work of impact exactly corresponds to that energy which is necessary to rupture the specimen. The ideal fall, such that the energy of the hammer is just sufficient to bring the specimen to rupture, can naturally only be reached by trial. Through over-massive heavy blows, totally false, wholly different results are obtained, for in such cases the loss through local effects, deformations of the hammer, and shaking of the machine reach a value which entirely obscures the result sought after.

4. The testing of the specimen by means of increasing heights of fall, as also by repetition of blows from the same height which are insufficient to cause rupture, shows no new feature. The experiments are thereby rendered only circumstantial, the errors are multiplied, and the judgment of their influence upon the result is made difficult.

5. The arrangement of the experiment with one-sided fast-

ening is not to be recommended. The break occurs in the vicinity of the clamped section, in which place the resistance to strain is greatly weakened by the clamping, and it is not a good arrangement for many reasons.

Upon the basis of the foregoing principles the main part of his experiments were carried through. Specimens were freely supported at two points, and broken by a single blow of the proper energy.

Thus far the discussion of the tests has dealt only with beams, supported at the ends and struck by a blow at the centre. The same principle of reasoning applies to compression or tension tests. In this case, however, the distinctions between the first period of impact causing the local compression, and the subsequent period in which the deformation of the entire specimen occurs are not so clear of comprehension, since the two effects are involved in one. In this case the local deformation if elastic becomes simply a longitudinal vibration traversing the length of the specimen. If the length of the specimen and the velocity of transmission of sound in the direction of impact be such that the reflection of this vibration occur isochronously with that of the rebound of the entire specimen, we have again the case as in the beams of complete restoration of energy to the hammer and the specimen remaining without vibration. On the other hand, if the opposite phase of this vibration occur at departure, we have a condition of minimum restoration of energy to the hammer and maximum vibration retained by the specimen. Both these cases are perfect elastic impact and are the limiting possibilities. Inelastic or dead impact lies between the two. It must be understood that the terms "elastic" and "dead" impact refer only to the local deformation and not to the action of the specimen as a whole, which acts as a "cushion" between the hammer and the anvil, as explained on page 243.

In the case of a long prismatic bar struck upon the end, the entire energy of the blow may be taken up in the vibration due to local compression.

Let us suppose two such bars to strike end to end. Let $l_1 l_2$ be their lengths, $w_1 w_2$ their weights per unit of length, S_1 and S_2 the velocities of transmission of sound longitudinally, respectively. Suppose $\frac{l_1}{S_1}$ less than $\frac{l_2}{S_2}$ and $S_1 w_1$ less than $S_2 w_2$, then

M. de St. Venant (1867) has shown that

$$k = 2\frac{l_1 w_1 + l_2 w_2}{l_2 w_2} \times \frac{w_2 s_2}{w_1 s_1 + w_2 s_2} - 1$$

where k is the ratio of the velocity of recoil to that of approach. If the two bars are exactly alike, this equation shows $k = 1$, or the energy of rebound is equal to that of approach, as with isochronous elastic impact. For the same material, when $w_1 = w_2$ and $S_1 = S_2$, this formula reduces to

$$k = \frac{l_1}{l_2}, \text{ simply}$$

which signifies that the velocity of recoil from the common centre of gravity of the two is the same as though the shorter bar struck one of its own size. In other words, if the initial velocity of the longer bar be zero, the velocity of the shorter bar after impact would always be reduced to zero (see an article in *The Engineer*, London, for Feb. 15, 1867). The equation for the velocity of sound in a body is well known,

$$S = \sqrt{\frac{gE}{w}}$$

where E is Young's modulus of elasticity in the direction of transmission and w is the weight per unit volume.

COMPRESSION AND TENSION.

Taking up now the theoretical equations for impact in compression or tension of a specimen fixed rigidly at one end to an anvil, so that the body acts as a "cushion" between the hammer and the anvil, as heretofore explained; we will assume the case of dead impact, and that the velocities of the particles are proportional to their distances from the fixed end, c being the velocity of the point of impact. Then

$$v = c\frac{x}{l}.$$

The hypothetical transposed mass m_o placed at the point of impact is then derived as follows:

$$m_o c^2 = \int_o^l mc^2 \frac{x^2}{l^2} dx = \frac{ml}{3} c^2 \qquad (42)$$

Whence $m_o = \frac{ml}{3}$ or one-third the total mass of the specimen.

Whence, following similar reasoning to that applied to the beams,

$$c = \left(\frac{A}{A+m_o}\right) V_a = \left(\frac{A}{A+\frac{1}{3}D}\right) V_a \tag{43}$$

The work stored in the specimen at any deflection y is, from the static relations,

$$K = \frac{Ea}{2l} y^2 \tag{44}$$

$$\text{Let } S = \frac{2K}{y^2} = \frac{Ea}{l} = \text{constant} \tag{45}$$

a being the cross-sectional area of the specimen. The greatest deflection under a static load of Q is

$$\delta = \frac{Ql}{Ea} = \frac{Q}{S} \tag{46}$$

The formulæ given in pages 336 to 341 may be followed throughout with these values.

The time-deflection curve referred to ordinates passing through the deflection produced by static load of Q is therefore

$$Y = v_b \sqrt{\frac{M}{S}} \sin\left(T\sqrt{\frac{S}{M}}\right) \tag{47}$$

$$Y_1 = v_b \sqrt{\frac{M}{S}} \tag{48}$$

$$T_1 = \frac{\pi}{2}\sqrt{\frac{M}{S}} \tag{49}$$

The time of one semivibration (with hammer and specimen acting together) is evidently

$$2T_1 = \pi\sqrt{\frac{M}{S}} = \pi\sqrt{\frac{Q+\frac{1}{3}G}{g} \times \frac{l}{Ea}} = \pi\sqrt{(A+\tfrac{1}{3}D)\frac{l}{Ea}} \tag{50}$$

Compare with equation (39)

After separation of the weight from the specimen, the time of vibration of the specimen alone is

$$\pi\sqrt{\frac{\frac{1}{3}Gl}{gEa}} = \pi\sqrt{\frac{Dl}{3Ea}} \tag{51}$$

To eliminate v_δ from equation, as before

$$y_1 = \delta + \sqrt{\delta^2 + \frac{Mc^2}{S}}$$

and

$$Y_1 = \frac{Ql}{aE}\sqrt{1 + \frac{aE}{(Q+\frac{1}{3}G)l} \times 2H} \qquad (52)$$

The stress per unit of area is then

$$P_1 = \frac{E}{l}(Y_1 + \delta) = \delta\frac{E}{l} + \frac{Q}{a}\sqrt{1 + \frac{aE}{(Q+\frac{1}{3}G)l} \times 2H}$$

$$= \frac{Q}{a}\left(1 + \sqrt{1 + \frac{aE}{(Q+\frac{1}{3}G)l} \times 2H}\right) \qquad (53)$$

It should be noted here also, as in the case of the beams, that when the weight falls vertically the time of actual contact before rebound occurs, is greater than $2T_1$, by the amount $2t_\delta$, given by equation (21) page 336. The time of vibration in this case of direct compression or of tension is the same as that of a simple pendulum whose length is

$$\frac{(Q+\frac{1}{3}G)}{S} = \frac{(Q+\frac{1}{3}G)}{Ea}l$$

DERIVATION OF THE TIME-DEFLECTION EQUATION.

The equation between time and deflection may be derived more simply as follows, but the result is in a less convenient form. We will use the same notation as before.

$$t_1 = ad = \sqrt{\frac{M}{S}}\ \text{arc tan}\left(\frac{C}{\delta}\sqrt{\frac{M}{S}}\right)$$

$$= \sqrt{\frac{M}{S}}\ \text{arc cos}\left(\frac{-\delta}{\sqrt{\frac{M}{S}C^2 + \delta^2}}\right)$$

$$Cd = \sqrt{\frac{M}{S}}\ \text{arc cos}\left(\frac{y-\delta}{\sqrt{\frac{M}{S}C^2 + \delta^2}}\right)$$

Let us consider first the case, which is the more complicated, where the hammer falls vertically so that the energy Qy_1 is added to its energy at instant of contact.

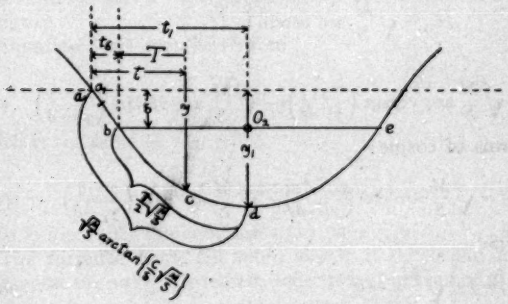
Equating the kinetic and potential energies at any point of deflection y,

$$M\frac{c^2}{2}+Qy=\frac{Mv^2}{2}+\frac{S}{2}y^2 \tag{61}$$

Whence

$$v^2=\frac{Mc^2+2Qy-Sy^2}{M} \tag{62}$$

FIG. 8.



But

$$v=\frac{dy}{dt}$$

hence

$$\frac{dy}{dt}=\sqrt{\frac{Mc^2+2Qy-Sy^2}{M}} \tag{63}$$

and

$$dt=dy\frac{\sqrt{M}}{\sqrt{Mc^2+2Qy-Sy^2}} \tag{64}$$

From (61), at maximum deflection y_1 $v=o$.

$$Mc^2=Sy_1^2-2Qy_1, \text{ or since } Q=s\delta,$$

$$Mc^2=Sy_1^2-2S\delta y_1 \tag{65}$$

Equation (64) may then be written in the form

$$dt=\frac{-\frac{dy}{y_1-\delta}}{\sqrt{2\frac{Y_1-y}{y_1-\delta}-\left(\frac{y_1-y}{y_1-\delta}\right)^2}}\times\sqrt{\frac{M}{S}} \tag{66}$$

Integrating which gives

$$t = -\sqrt{\frac{M}{S}} \text{ arc versin } \left(\frac{y_1 - y}{y_1 - \delta}\right) + C_1 \qquad (66a.)$$

To find C_1 we have for $t = o$, $y = o$.
Hence

$$o = -\sqrt{\frac{M}{S}} \text{ arc versin } \left(\frac{y_1}{y_1 - \delta}\right) + C_1$$

$$C_1 = \sqrt{\frac{M}{S}} \text{ arc versin } \left(\frac{y_1}{y_1 - \delta}\right)$$

Whence

$$t = \sqrt{\frac{M}{S}} \text{ arc versin } \left(\frac{y_1}{y^1 - \delta}\right) - \sqrt{\frac{M}{S}} \text{ arc versin } \left(\frac{y_1 - y}{y_1 - \delta}\right) \qquad (67)$$

or in terms of cosine:

$$t = \sqrt{\frac{M}{S}} \text{ arc cos } \left(\frac{-\delta}{y_1 - \delta}\right) - \sqrt{\frac{M}{S}} \text{ arc cos } \left(\frac{y - \delta}{y_1 - \delta}\right) \qquad (68)$$

From (65)

$$y_1 = \delta \pm \sqrt{\frac{M}{S} c^2 + \delta^2} \qquad (68a.)$$

The sign of the radical being + for values below the horizontal and — above. Hence for values below the horizontal, equation (68) becomes

$$t = \sqrt{\frac{M}{S}} \text{arc cos } \left(\frac{-\delta}{\sqrt{\frac{M}{S} c^2 + \delta^2}}\right) - \sqrt{\frac{M}{S}} \text{ arc cos } \left(\frac{y - \delta}{\sqrt{\frac{M}{S} c^2 + \delta^2}}\right) \qquad (69)$$

The first member in these three equations, which is the constant of integration, represents in the time required from contact to maximum deflection, shown as *ad* in the figure, the cosine is negative in the equation showing the arc to be greater than $\frac{\pi}{t}$, which is also evident from the figure, knowing that the line *be* at deflection of δ due to the static load Q, is the centre of vibration. This is shown in equation (68) by making $y = y_1$.

The second member of the equation represents the time from the time of deflection y to the maximum y_1, shown by *cd* in the figure, the difference of the two being the time t.

By making $y = \delta$, the time of deflection t_δ is

$$t_\delta = \sqrt{\frac{M}{S}} \text{ arc cos}\left(\frac{-\delta}{y_1 - \delta}\right) - \frac{\pi}{2}\sqrt{\frac{M}{S}} \tag{70}$$

From the foregoing remarks it is clear that

$$\frac{\pi}{2}\sqrt{\frac{M}{S}}$$

is the time for half a semivibration, as is also evident from bd in the figure.

Equation (70) may be written

$$t_\delta = \sqrt{\frac{M}{S}} \text{ arc tan } \frac{c}{\delta}\sqrt{\frac{M}{S}} - \frac{\pi}{2}\sqrt{\frac{M}{S}}$$

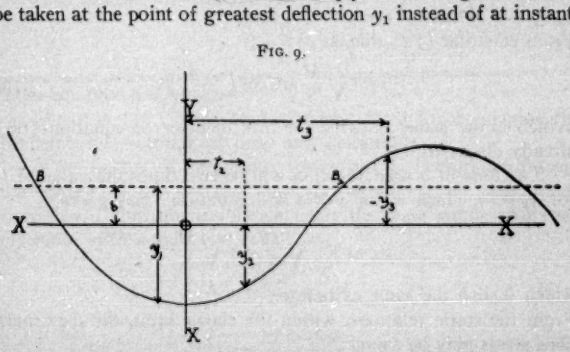
Which is the same as

$$t_\delta = \sqrt{\frac{M}{S}} \text{ arc tan}\left(\frac{\delta}{c}\sqrt{\frac{S}{M}}\right) \tag{71}$$

which is identical with equation (31) page 339.

The formulæ work out more simply if the origin for time be taken at the point of greatest deflection y_1 instead of at instant

FIG. 9.



of contact, a; for turning back to equation (66a.) we then have for $t_2 = o$, $y = y_1$ whence the constant of integration becomes o and the equation for time deflection becomes:

$$t_2 = -\sqrt{\frac{M}{S}} \text{ arc cos}\left(\frac{y - \delta}{y_1 - \delta}\right) \tag{72}$$

From which equation the same results as before may be determined. This moreover gives us a ready means of disentangling y from the function, and writing the equation as follows in direct terms of y and t_2:

$$y=(y_1-\delta)\cos\left(t_2\sqrt{\frac{S}{M}}\right)+\delta \tag{73}$$

Moreover, if we take the origin for y on the line be (Fig. 8) so that the new origin of ordinates is O_2, in the figure,

$$y=y_2+\delta$$

Whence equation (73) becomes:

$$y_2=(y_1-\delta)\cos\left(t_2\sqrt{\frac{S}{M}}\right) \tag{74}$$

Substituting the value for y_1 from equation (68a)

$$y_2=\pm\cos\left(t_2\sqrt{\frac{S}{M}}\right)\times\sqrt{\frac{M}{S}c^2+\delta^2} \tag{75}$$

The new co-ordinates are shown in Fig. 9 for clearness.

The time of contact will be two times the value of t_2 for $y_2=-\delta$, which is for $y=o$.

From equation (72) this is

$$2t_2=2\sqrt{\frac{M}{S}}\operatorname{arc}\cos\left(\frac{-\delta}{y_1-\delta}\right) \tag{76}$$

Which is the same as twice the first member of equation (68) already discussed.

The time of a semivibration will be two times the value of t_2 for $y_2=o$ which is for $y=\delta$ and equation (72) gives

$$2t_2=2\times\frac{\pi}{2}\sqrt{\frac{M}{S}}=\pi\sqrt{\frac{M}{S}} \tag{77}$$

which is also the same as before.

From the static relations, within the elastic limit, the maximum fibre stress may be found:

In bending

$$P_b=\frac{6hE}{l^2}y_1$$

$$P_b=\frac{6hE}{l^2}\left(\delta+\sqrt{\frac{M}{S}c^2+\delta}\right)$$

$$P_b=\frac{6h}{l^2}\times\frac{QE}{S}\left(1+\sqrt{1+\frac{S}{M}\times\frac{2gH}{}}\right) \tag{78}$$

$$P_b=\frac{Qlh}{8J}\left(1+\sqrt{1+\frac{48EJ\times 2H}{(Q+\frac{17}{35}G)l^3}}\right)$$

The last is identical with equation (41) page 341.

In compression:

$$P_c=\frac{E}{l}y_1 \tag{79}$$

$$P_c=\frac{1}{l}\times\frac{QE}{S}\left(1+\sqrt{1+\frac{S}{M}\times 2gH}\right) \tag{80}$$

$$P_c=\frac{Q}{a}\left(1+\sqrt{1+\frac{aE\times 2gH}{(Q+\frac{1}{3}G)l}}\right) \tag{81}$$

The last is identical with equation (53) page 346.

The work performed is

$$K_1=\frac{S}{2}y_1^2 \tag{82}$$

$$y_1=\frac{Q}{S}\left(1+\sqrt{1+\frac{S}{M}2gH}\right) \tag{83}$$

from equation (68a).

Equation (75) is doubtless the best form for expressing the fundamental relations of time and deflection.

If the impact be horizontal, the term Qy_1 is eliminated from the energy of the hammer, and the equations are very much simplified. They are as follows, using the same number for easy reference with a subscript c:

$$M\frac{c^2}{2}=M\frac{v^2}{2}+\frac{S}{2}y^2 \tag{61c}$$

$$v^2=\frac{Mc^2-Sy^2}{M}$$

$$\frac{dv}{dt}=\frac{\sqrt{Mc^2-Sy^2}}{\sqrt{M}} \tag{63c}$$

$$dt = dy \frac{\sqrt{M}}{\sqrt{Mc^2 - Sy^2}} = \sqrt{\frac{M}{S}} \times \frac{dy}{\sqrt{\frac{M}{S}c^2 - y^2}} \qquad (66c)$$

$$t = \sqrt{\frac{M}{S}} \text{ arc sin } \frac{y}{c} \sqrt{\frac{S}{M}} + C_1$$

Or since from (65-c),

$$y_1 = c\sqrt{\frac{M}{S}}$$

$$t = \sqrt{\frac{M}{S}} \text{ arc sin}\left(\frac{y}{y_1}\right) + C_1 \qquad (66a\text{–}c)$$

For $t = o$, $y = o$, whence $C_1 = o$

Therefore the equation is simply

$$t = \sqrt{\frac{M}{S}} \text{ arc sin } \left(\frac{y}{y_1}\right) \qquad (68c)$$

From which,

$$y = y_1 \sin \left(t\sqrt{\frac{S}{M}}\right) \qquad (68^1c)$$

and since

$$y_1 = c\sqrt{\frac{M}{S}}$$

$$y = c\sqrt{\frac{M}{S}} \sin \left(t\sqrt{\frac{S}{M}}\right) \qquad (68^2c)$$

The time of contact is in this case the same as that for a semi-vibration, and is two times the value for t when $y = y_1$. From (68c)

$$2t_1 = 2 \times \frac{\pi}{2}\sqrt{\frac{M}{S}} = \pi\sqrt{\frac{M}{S}} \qquad (70c)$$

which is exactly the same as we found for vertical impact equation (70).

There is no advantage in transposing co-ordinates in this case, but for the sake of uniformity we will do so.

$$t_2 = t - t_1 \text{ or } t = t_2 + t_1 = t_2 + \frac{\pi}{2}\sqrt{\frac{M}{S}}$$

Placing this value in equation (68c)

$$t_2+\frac{\pi}{2}\sqrt{\frac{M}{S}}=\sqrt{\frac{M}{S}}\text{ arc sin }\left(\frac{y}{y_1}\right)$$

Whence

$$t_2=\sqrt{\frac{M}{S}}\text{ arc cos }\left(\frac{y}{y_1}\right) \qquad (72c)$$

and

$$y=y_1\cos\left(t_2\sqrt{\frac{S}{M}}\right)$$

$$y=c\sqrt{\frac{M}{S}}\cos\left(t_2\sqrt{\frac{S}{M}}\right) \qquad (75c)$$

The time of contact or semivibration is

$$2t_2 \text{ for } y=o=\pi\sqrt{\frac{M}{S}}, \text{ as in (70c)}, \qquad (76c)$$

The maximum fibre stress:

In bending,

$$P_f=\frac{6hE}{l_2}\times c\sqrt{\frac{M}{S}} \qquad (78c)$$

In compression or tension,

$$P_c=\frac{E}{l}\times c\sqrt{\frac{M}{S}} \qquad (80c)$$

The work performed is

$$K_1=\frac{S}{2}y_1^2=\frac{M}{2}c^2 \qquad (82c)$$

There is no transformation for the y ordinate in this case.

Equations (75) and (75c) may be taken as the fundamental equations of the time-velocity curve, for vertical and horizontal impact respectively, with the origin of co-ordinate taken at the time of maximum deflection and at a deflection in the former case produced by the static load of the hammer, and zero deflection in the latter case; provided always that the hammer and specimen remain in contact, with inelastic local deformation.

These formulæ apply equally in the case of direct compression

or direct tension, only that the values of the constants M and S are different.

For compression or tension

$$M=(A+\tfrac{1}{3}D)=\frac{Q+\frac{1}{3}G}{g}$$

$$S=\frac{aE}{l}$$

While for the beams they are

$$M=(A+\tfrac{17}{35}D)=\frac{Q+\frac{17}{35}G}{g}$$

$$S=\frac{48EJ}{l^3}$$

Where Q = weight of hammer, G weight of specimen.
g = acceleration due to gravity.
E = modulus elasticity.
a = cross-sectional area.
J = moment inertia of cross-section.
l = length of span.
D = mass of specimen $\frac{G}{g}$

ELASTIC LIMIT UNDER IMPACT.

From equations (78c) and (80c) it is seen that for *horizontal impact*, the stress varies directly with the velocity at impact, other things being constant for a given specimen, on the assumption that the stress is proportional to the deflection. *The elastic limit* of the specimen is therefore the point where *the actual curve of the tracing diverges from the theoretical curve*. This may be found by plotting the two curves to scale. The result is apt to be indefinite, however.

A more definite result, though open to the objection as to whether the elastic limit under repeated blows differs from that under a single blow, is obtained by plotting the deflections produced by successive blows of gradually increasing heights against the velocity of the hammer at first contact. This ratio will evidently be constant up to the elastic limit, when it will begin to increase.

In vertical impact the latter method will not be correct, as is evident from equations (78), (80), and (83). The value

$$\left(v_1\frac{S}{Q}-1\right)^2-1$$

plotted against the velocity squared or the height of fall H should be used in this case. The square of the deflections against the height of fall, however, will give *approximate* results.

RECAPITULATION OF SOME OF THE MORE IMPORTANT DEDUCTIONS FROM THE THEORY OF IMPACT.

I. GENERAL LAWS OF IMPACT BETWEEN TWO FREE BODIES WHOSE MASSES ARE A AND B.

1. The two bodies form a system the motion of whose mutual centre of gravity can be altered only by a force external to the system. It is not altered by any kind of impact between the two bodies. The velocity of the mutual centre of gravity is

$$V=\frac{v_aA+v_bB}{A+B}$$

2. Assuming the motion of A and B to be along the line joining their centres, and no loss of energy to occur by impact, their final velocities relative to their common centre of gravity will be the same as their initial, but in the opposite direction, the internal energy of the system remaining the same. If they do not rebound, but "fall dead" upon impact the united mass then continues with the velocity V, but the internal energy has entirely disappeared as velocity, being converted into vibration, heat, etc.

3. The change in momentum of the two bodies is brought about by the action of a mutually repellent force F, which is the direct result of the elastic compression of the material of which the bodies is composed or of a "cushion" between the two bodies. This cushion may be an intermediate substance or it may be electrical or similar stress. In any case the force F must require *time* in which to act, consequently contact between two incompressible bodies is a fallacy of conception. The intensity of this force at any instant is equal to the change in

momentum produced divided by the time required to produce the change:

$$F = \frac{dv}{dt} m.$$

Momentums must be considered with reference to the motion of the mutual centre of gravity of the two bodies, or with reference to some point external to the system having uniform or zero motion.

II. THE RELATIONS OF THE SPECIMEN UNDER TEST TO THE GENERAL LAWS OF IMPACT.

1. The specimen tested by impact is really a *cushion* between the two impacting bodies, which are the hammer A and the anvil B.

2. In order to obtain correct results from the tests, and in order that the formulæ shall apply, the proportions of the anvil to the hammer and its velocity must be such that its relative motion may be neglected, and likewise the velocity of the mutual centre of gravity. The following conditions must be realized:

$$V = \frac{Av_a}{A+B} = > o$$

by a neglible amount.
Also the relative velocity of

$$A = \frac{B}{A+B} v_a$$

must approach its actual velocity v_a by such an amount that the difference of the kinetic energies

$$\left(\frac{A}{A+B} v_a\right)^2 A \text{ and } v_a^2 A$$

is negligible.

3. If the specimen under test were conceived of as *massless* the problems of impact would be made very simple. The mutual repellent force F would then be produced purely by the stress due to its distortion, and if elastic all the energy would be returned to the hammer, and whether elastic or not, no energy would be retained in mechanical vibrations. The force F at any

instant could be determined from the curve of the tracing, figures 1 and 2, pp. 246 and 249, by drawing tangents, from the relation,

$$F = \frac{d^2y}{dt^2}A = \frac{dv}{dt}A$$

Or in the case of vertical fall

$$F = \left(\frac{d^2y}{dt^2}A\right) + Q$$

Q being the weight of the hammer $= g \times A$.

The work done in breaking the specimen would be the loss of energy of the hammer, which is the difference in its energy before and immediately after contact, the final velocity being determined from the tracing. In the case of vertical fall the remaining potential energy of the hammer at contact, Qy_1, must be added to its kinetic energy.

4. Taking into consideration the *mass* of the specimen itself (but not its weight, the effect of which is small, and entirely disappears in horizontal impact), two distinct actions occur. The momentum of the hammer has to overcome not only the stress due to distortion of form, but also the inertia of the particles of the specimen. The force acting between the hammer and the specimen is therefore made up of two parts, f due to distortion of form and f_1 due to inertia of the particles:

$$F = f + f_1$$

The compression occurring at the point of contact is due to the entire force F, but since there is no limit to the value of f_1 it is evident that if the velocity of the blow be great F may become intense enough to actually crush the material at the point of contact before the regular distortion takes place. This is particularly true in the case of beams.

5. Two conditions are possible, first when this local crushing is inelastic or permanent and second when it is elastic and springs back. Take for example the case of a beam supported at the ends and struck in the middle, which is the simplest to imagine. The local crushing reaches its maximum by the time the centre of the beam receives the same velocity as the hammer. Imagine a mass m_o placed at the centre of a beam of such quantity that

its effect upon the hammer will exactly correspond to that of the original mass of the entire beam, and consider the beam then as massless. By the law of impact, as soon as the compression has become maximum so that both hammer and centre point of beam are moving in unison, their mutual velocity is

$$c = \frac{A}{A + m_o} v_a$$

In the supposed case when the compression is dead or inelastic, the energy to produce the distortion of the beam is

$$\frac{c^2}{2}(A + m_o) + Qy_1$$

the difference between this and

$$\left(\frac{v_a^2}{2}A + Qy_1\right)$$

being lost in producing the local compression.
This case is illustrated in Fig. 4.

6. At departure both beam and hammer have the same velocity c, consequently a further loss of energy occurs of an amount

$$\frac{c^2}{2}m_o$$

which is retained by the beam in the form of mechanical vibrations.

7. If the form of the curve of the deflection of the beam be known, and the velocities of its particles be considered as proportional to their deflections, the value of m_o may be determined from the following general principle:

In a system consisting of several parts, which is so connected by its geometrical proportions and fixture to stationary base, that the relative velocities of each part may be determined, any part may be transposed so as to move with a new velocity v_2 provided its mass be changed in the inverse ratio of the squares of the new to the old velocities, *without in anywise affecting* the velocities of any of the other parts, nor the forces acting upon them. The force or forces producing the motions of the entire system will in no wise be changed thereby.

Thus if v_1 be the velocity of m_1 it may be transposed to move with a new velocity v_2, provided its new mass

$$m_2 = \frac{v_1^2}{v_2^2} m_1$$

without in any way affecting the system or its reaction upon an external body.

Assuming the elastic form of the curve of the beam to be the same under impact as in static loading, this value of m_o is $\frac{17}{35}\frac{G}{g}$ when $\frac{G}{g}$ is the mass of the entire beam. For compression or tension

$$m_o = \frac{1}{3}\frac{G}{g}.$$

8. The second kind of impact is when this local compression is elastic, and recovers. Here two cases are possible, isochronous elastic impact, when the recovery of the compressed area takes place in the same phase with that of the rebound of the beam as a whole; and unharmonic elastic impact, when the two phases are not together or directly opposed. These cases are illustrated in Figs. 5 and 6. In the first case the beam is left without vibrations, the entire energy being returned to the hammer. In the second case the beam retains vibrations, at the expense of the hammer, and even though the material be *perfectly elastic the hammer may rebound with actually less energy* than in the case of the inelastic impact. Thus the loss of energy of the hammer is not necessarily due to inelasticity of the material. In fact the first case of complete restoration of energy to the hammer is practically almost hypothetical and only possible under certain definite relations.

III. DEVELOPMENT OF THE FORMULÆ FOR THE TIME-DEFLECTION RELATIONS WITHIN THE ELASTIC LIMIT.

For the time-deflection curve where the weight falls vertically, for inelastic local compression, the hammer and specimen remaining united.

$$t = \sqrt{\frac{M}{S}} \arccos \frac{-\delta}{y_1 - \delta} - \sqrt{\frac{M}{S}} \arccos \left(\frac{y-\delta}{y_1-\delta}\right) \qquad (68)$$

$$y_1 = \delta \pm \sqrt{\frac{M}{S}c^2 + \delta^2} \tag{68a}$$

The sign of the radical above is + for values of y below the horizontal and — above, the origin for t and y in the above equation being taken at instant of contact.

Taking the origin at the instant of maximum deflection, y_1, and at the amount of deflection δ produced by the static load Q the following equations are obtained:

$$y = y_2 + \delta$$

$$t = t_2 + t_\delta + \frac{\pi}{2}\sqrt{\frac{M}{S}}$$

$$t_2 = -\sqrt{\frac{M}{S}} \operatorname{arc\,cos}\left(\frac{y-\delta}{y_1-\delta}\right) \tag{72}$$

$$y_2 = \pm \cos\left(t_2\sqrt{\frac{S}{M}}\right) \times \sqrt{\frac{M}{S}c^2 + \delta^2} \tag{75}$$

Time of contact =

$$2t_2 \text{ for } y_2 = -\delta$$

$$= 2\sqrt{\frac{M}{S}} \operatorname{arc\,cos}\frac{-\delta}{y_1-\delta} \tag{76}$$

Time of semivibration =

$$2t_2 \text{ for } y_2 = 0$$

$$= \pi\sqrt{\frac{M}{S}} \tag{77}$$

This is the same as the time for a semivibration of a pendulum whose length is $\frac{Mg}{S}$

From the static relations, within the elastic limit, the maximum fibre stress expressed in terms of the weights and height of fall is, in bending

$$P_b = \frac{6h}{l^2} \times \frac{QE}{S}\left(1 + \sqrt{1 + \frac{S}{M}\frac{2gH}{}}\right) \tag{78}$$

or

$$P_b = \frac{Qlh}{8J}\left(1 + \sqrt{1 + \frac{48EJ \times 2H}{(Q + \frac{1}{35}G)l^3}}\right) \tag{79}$$

In compression or tension:

$$P_1 = \frac{1}{l} \times \frac{QE}{S}\left(1 + \sqrt{1 + \frac{S}{M}\,2gH}\right) \tag{80}$$

or

$$P_1 = \frac{Q}{a}\left(1 + \sqrt{1 + \frac{aE \times 2H}{(Q + \frac{1}{3}G)l}}\right) \tag{81}$$

Work performed,

$$K_1 = \frac{S}{2} y_1^2 \tag{82}$$

If the impact be horizontal, the term Qy_1 is eliminated from the energy of the hammer, and the equations are much simplified.

For horizontal impact the equations are:

$$t = \sqrt{\frac{M}{S}}\ \text{arc sin}\left(\frac{y}{y_1}\right) \tag{68c}$$

$$y = c\sqrt{\frac{M}{S}}\ \sin\left(t\sqrt{\frac{S}{M}}\right) \tag{68^{2}c}$$

The origin for t and y being at the instant of contact.

Taking the origin for t_2 at the instant of maximum deflection, so as to correspond with the former equations, the following result:

$$t = t_2 + \frac{\pi}{2}\sqrt{\frac{M}{S}}$$

$$t_2 = \sqrt{\frac{M}{S}}\ \text{arc cos}\left(\frac{y}{y_1}\right) \tag{72c}$$

$$y = y_1 \cos\left(t_2\sqrt{\frac{S}{M}}\right)$$

$$y = c\sqrt{\frac{M}{S}}\cos\left(t_2\sqrt{\frac{S}{M}}\right) \tag{75c}$$

The *time of contact* is the same in this case as that of semi-vibration and is

$$2t_2 \text{ for } y = o, = \pi\sqrt{\frac{M}{S}} \tag{77c}$$

This is the same as the time for a semivibration in the vertical impact.

The maximum fibre stress is:

In bending

$$P_b = \frac{6hE}{l^2} \times c \sqrt{\frac{M}{S}} \tag{78c}$$

In compression or tension

$$P_c = \frac{E}{l} \times c \sqrt{\frac{M}{S}} \tag{80c}$$

The work performed is

$$K_1 = \frac{S}{2} y_1^2 = \frac{M}{2} c^2 \tag{82c}$$

The foregoing equations, except as stated for the values of P, apply to either bending or compression and tension tests, when the proper values of the constants M and S are substituted. They are as follows:

M for bending $= (A + \frac{17}{35} D) = (Q + \frac{17}{35} G) \frac{1}{g}$

For compression or tension $= (A + \frac{1}{3} D) = (Q + \frac{1}{3} G) \frac{1}{g}$

S for bending $= \frac{48EJ}{l^3}$

For compression or tension $= \frac{Ea}{l}$

Nomenclature used in the above is as follows:

$A =$ the mass of hammer $= \frac{Q}{g}$

$Q =$ weight of hammer.

$D =$ the mass of the specimen $= \frac{G}{g}$

$G =$ weight of specimen.

$\partial =$ deflection of specimen due to static load Q.

$c =$ velocity of combined mass after the local deformation has occurred.

t and $y =$ times and deflections counted from the instant of impact and zero deflection of the specimen.

t_2 and y_2 = the same counted from the instant of maximum deflection and (for vertical impact) the deflection produced by the static load Q. For horizontal impact y_2 is the same as y.

y_1 = the total deflection of the specimen at its maximum deflection.

H = height of fall of hammer before contact.

h = depth of beam, of whatever shaped section provided it be symmetrical with the axis.

a = cross-sectional area.

l = length of span for beams, or length of specimen for compression or tension.

J = moment inertia of cross-section with respect to the neutral plane.

K = energy or work.

g = acceleration of gravity.

P = unit fibre stress.

IV. OBSERVATIONS DERIVED FROM TESTS.

1. Dr. A. Gessner, who has made a very careful comparison of the time deflection curve obtained from tests with the theoretical equation draws the following conclusions (his tests were made upon cast-iron beams with a span of 50 cm., and depth of about 2 cm.; the hammer weighed from 10 to 20 kilos., and the height of fall from 1.5 to 5 cm.; the ratio of $\frac{G}{Q}$ was less than $\frac{1}{4}$; the beams for rupture were broken by a single blow):

a. The theoretical and actual curves are practically identical.

b. The assumption of inelastic local compression is correct. The form of the curve of the axis of the beam is practically the same as for static loading. Hook's law holds for impact as well as static stress, within the elastic limit. The loss of energy to the anvil in impact tests is a very important consideration, especially in compression tests. In beams with suitable proportions this loss is neglible.

c. The total breaking work and the total deflections in static and in impact tests differ but little in cast-iron of good quality.

d. The characteristics of the material are shown with as much clearness in impact as in static tests.

e. The remaining energy of the weight after breaking the specimen should be less than 30 per cent. of its initial energy, and the weight of the hammer should be at least four times that of the specimen. The ideal height of fall would be such that the energy of the hammer is just sufficient to break the specimen.

f. Over-heavy blows give totally false results, for the losses in local effects reach a value which entirely obscures the results sought after.

g. Tests made by increasing heights of fall, as also by repetition of blows from the same height, are of only circumstantial value, errors are thereby multiplied and it is difficult to judge the influence upon the results.

h. On the whole, impact tests are well adapted for determining the qualities of the materials.

ADDENDUM.

The foregoing article upon the Theory of Impact has been developed with the purpose of determining the fundamental principles underlying impact tests in such a way that the true relationships and influences of all the quantities involved might be clearly exhibited. The attempt has been made to develop the theoretical and mathematical part of the discussion progressively from the simple fundamental mechanical relations of force, mass, time, and space, so that the results may be readily comprehended without very deep study into theoretical mechanics and mathematics.

A clear and simple presentation of the relation of the specimen under test to the laws of impact I have been unable to find in literature, and it is my hope that this article will in part at least fill the need.

While the discussion and a large part of the development of formulæ is original, so far as I am aware, I owe considerable assistance to the German work of Dr. A. Gessner, professor in the Technical High School in Vienna referred to in the text, "Ueber die Beanspruchung Freiaufliegender Träger durch Stoss." Suggestions for the development of some of the formulæ were obtained from Merriman's "Mechanics of Materials" and Rankine's "Applied Mechanics." Wherever information or equations have been used, acknowledgment has been made in the text and the reference given.

SECTION OF PHYSICS AND CHEMISTRY

(Stated Meeting held Thursday, June 10, 1909.)

A CRITICAL STUDY OF THE NATURAL CHANGES OCCURRING IN FATS AND OILS.*

BY

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(Contribution from the Food Research Laboratory, Bureau of Chemistry, United States Department of Agriculture.)

UPON exposure to the forces of Nature, fats and oils undergo changes in their physical, chemical, and organoleptic properties. The color is frequently altered and the odor and taste become disagreeable. Not only the physical constants like melting point and density, but also the chemical constants, *e.g.*, acid value, and iodine, saponification, Hehner and Reichert-Meissl numbers, change. The changes in the chemical constants, which, in the case of each sample of fat or oil, depend upon the particular forces which have been at work upon that sample, prove that the chemical composition of the fat has altered.

Fats and oils, in which these changes have occurred, were formerly termed rancid; however, during recent years the distinction has been made between acid fats and oils, rancid fats and oils, and fats and oils both acid and rancid. The agents which act upon fats and oils include organisms, their enzymes, tissue enzymes, natural and artificial light, heat, and the gases of the atmosphere. It is the purpose of this paper to review the various researches which have been made concerning the natural changes in fats, and to give a résumé of the views of different investigators with respect to the causes of these changes. With that end in view, there will be discussed in order the influences of the following agents:

* Presented at the Seventh International Congress of Applied Chemistry, London, 1909.

Organisms and the enzymes secreted by them.
Tissue enzymes.
Gases of the atmosphere.
Light.
Heat and cold.
Rancidity and acidity.

THE ACTION OF ORGANISMS AND THEIR ENZYMES UPON FATS AND OILS.

Certain bacteria, moulds and yeasts, have power to decompose fats and oils, provided sufficient nutriment—which almost invariably implies nitrogenous material—be present. The nature of the decomposition depends upon the organism or organisms which are at work. Many of these organisms secrete lipolytic enzymes which attack the glycerides; others act directly.

Virchow [1] states that aged genuine butters possess a fairly low Reichert-Meissl number and a high, frequently an exceedingly high, acidity. He ascribes the high acidity to a decomposition of the butter-fat, especially the glycerides of the volatile fatty acids, produced by lower organisms. The decrease in the Reichert-Meissl number is explained by volatilization or further decomposition of the free lower fatty acids. These butters always had a very strong butter-odor; and, when decomposition was far advanced, the characteristic odor of Roquefort cheese often developed. Old spurious butters usually have a very low acidity, and their acidity never becomes as high as that of old true butters.

Kirchner [2] examined a number of samples of poppy oil and of the sesame oil, which in spite of most careful handling had become cloudy some time after the pressing. As a rule the cloudiness was produced by characteristic sickle-shaped bacteria, which were pointed at both ends. Kirchner also describes a fungus which he named *Elæomyces olei*. It grows in freshly pressed poppy oil, which offers it the necessary nourishment. The fungus decomposes the oil; its cells are surrounded by a stratum of liquid—a decomposition-product of certain constituents of the oil—of refractive power differing from that of the oil. Needle-like crystals, probably of an oil acid, occasionally are found between the cells. Gas bubbles are also produced. The fungus draws nitrogenous nourishment from those proteins

which enter the oil as unavoidable impurities during the pressing. Repeatedly filtered fresh oil and older clear oil do not nourish and support the fungus. While the fungus grows immersed in the poppy oil, it reproduces only by budding. When the oil, in which *Elæomyces olei* occurs, begins to dry and the latter comes in contact with the air, reproduction by spore-formation takes place. Several individuals grow together and empty their contents into one of the more central cells which then develops into a spore with very thick brown walls. *Elæomyces olei* probably belongs to the genus *Zygomycetes* species *ustilaginia*.

Ritsert [3] found that fresh fats were sterile or nearly so, while rancid fats (swine fat, cocoanut oil, butter, sausage fat), which were from five weeks to one year old, contained micro-organisms, both aerobic and anaerobic, including moulds (*oidia*), yeasts and cocci; bacteria (rod forms) were less common in occurrence. Swine fat was rendered, sterilized, and inoculated with pure culture of organisms from the rancid fats or with rancid fat itself. Experiments made at room temperature in diffuse daylight, and those made in a thermostat at 37°, gave about the same result. The organisms decreased, and usually the count was zero at the end of sixty days. Anaerobes lived somewhat longer than aerobes. The taste and smell of the fat remained unchanged, and no increase had occurred in its free acid content. The organisms of garden earth and of hay infusion, as well as butyric and lactic bacilli, were inoculated into fresh fat and allowed to act for two months, but failed to produce rancidity. When the bacteria were allowed to act upon fat for sixty days in direct sunlight, they died far more rapidly, but a rancid taste and smell developed and the free acid content of the fat increased. While Ritsert recognizes the rancid smell and taste, yet he ascribes rancidity to the splitting of fats into free fatty acids and glycerol.

Experiments were also made by Ritsert [4] to determine the rôle of organisms in the further decomposition of rancid fats. Samples of swine fat, rancid from the action of oxygen and light, were inoculated with pure culture of different organisms by means of platinum wire. After fourteen days colonies, visible to the naked eye, and consisting of moulds, yeasts and cocci, had developed about the points of inoculation. The organisms could be demonstrated at non-inoculated places upon the fat by remov-

ing samples with a platinum loop and plating them on gelatine. The presence of a great quantity of free fatty acid in a rancid palm kernel oil prevented the growth of organisms (moulds) upon the oil. From other experiments Ritsert decided that swine fat is not permeable to micro-organisms. He poured gelatine plates, cooled them on ice, then added a layer of half-cool pure swine fat 3 to 15 mm. thick, care being taken to prevent mixing of the fat and gelatine. Garden earth was placed on the solidified fat; even after five months the organisms of the earth had not penetrated the fat to the gelatine.

Arata [5] found that, when butter is kept in the air or under water, the quantity of volatile fatty acids (Reichert-Meissl-Wollny Number) sometimes increases and sometimes decreases. He states that the increase or decrease is largely due to the action of micro-organisms: Arata's experiments upon the physiological action of rancid butter are exceedingly interesting. A butter, that had been kept for three months exposed to the air, had an irritating and disagreeable odor; in the case of a butter that had been kept for a year the odor was more intense. The odor produced violent headache, irritation of the fauces and abundant salivation. When the year-old rancid butter was fed to a normal adult for ten days, it produced marked vomiting, intense abdominal pain and diarrhœa. The three-months-old rancid butter was fed during a period of twenty days; it gave rise to general weakness, serous diarrhœa and abdominal pain. Hence, rancid butter produces irritation of both the stomach and the intestines.

Spaeth [6] describes a butter which had been stored in a damp place and had assumed a green color. The fat, after filtration from the molten butter, was yellow in color and had a high acid value. The green residue upon the filter was washed with ether, to free it from fat, and then was examined under the microscope and found to contain *Penicillium glaucum*.

Sendtner [7] mentions a butter in which the taste had been totally destroyed by the growth of moulds. The acid degree at the same time had risen to an exceedingly high value.

Klecki [8] states that the acidity of butter increases more rapidly under ordinary conditions than under the influence of sunlight or of heat. The bacteria, to whose activity the acidity is due, are killed by sunlight, and are hindered in the production of acid by heat. However, a butter, stored in the sunlight or in a

warm place, may become rancid without becoming acid. Acidity is due first of all to bacterial action and depends less upon the action of air and light, while rancidity may be considered as the total product of all factors.

Filsinger [9] found that cacao-butter, which is extracted from the shells and other refuse (germs and fragments of the cotyledons), may have a very high acidity, due to the splitting of the fat. He suggests that micro-organisms, light and the oxygen of the air all play a part in this decomposition.

Biffin [10] discovered upon cocoanuts a fungus—one of the *Hypocreales*, probably belonging to the group of the *Nectrieæ*—which decomposed the oil of the nuts with the production of a pleasant etherial odor recalling that of amyl butyrate. The fungus contained a fat-splitting enzyme which hydrolyzed cocoanut oil and monobutyrin. The enzyme first emulsified the fat, then caused hydrolysis with the liberation of free fatty acid.

Amthor [11] has shown that the bouquet of rancid butter is due to the presence of ethyl butyrate. Fifty grammes of rancid butter were distilled with steam until 500 c.c. of distillate had collected. The distillate was exactly neutralized with alkali and was distilled. This second distillate was saponified by boiling for half an hour under a reflux condenser with an excess of alkali. It was then distilled; in this third distillate the presence of alcohol was proved by the iodoform and acetaldehyde tests. The solution remaining in the distilling flask was made acid with sulphuric acid and distilled. The distillate had the odor of butyric acid; the calcium content of the calcium salt, which was prepared from this distillate, showed that the acid was butyric acid with a slight admixture of fatty acids of higher carbon content. Hence, ethyl butyrate was present in the butter. Amthor believes that micro-organisms ferment the lactose of the butter to alcohol; simultaneously there is an hydrolysis of the glycerides, especially of butyrin, which is the least stable. The free butyric acid and the alcohol combine to form butyric ester. The quantity of this compound reaches a maximum, then a splitting occurs with the result that finally it is almost entirely destroyed. When this has occurred, the butter is tallow-like. In the rancidity of other fats odor plays a lesser part; the harsh taste has the leading rôle.

The effect of moulds upon butter has been studied by Hanus [12]

and by Hanus and Stocky.[13] A butter, which had been stored in a tin can in a moist place for four months, was completely covered by a layer of the mould *Mucor*. The butter had become a dirty yellow color, and had a cheese-like, rancid odor and a tallowy taste. The fat-constants of the mouldy butter differed from those of the same butter in the fresh condition, in that the acidity had increased enormously; the saponification, Reichert-Meissl and iodine numbers had decreased slightly, while the free volatile acids had increased somewhat. The quantity of unsaturated acids had not esentially changed. The *Mucor* had chiefly split the glycerides into free acid and glycerol; the glycerides of higher molecular weight were hydrolyzed sooner than those of lower molecular weight (volatile acids). The mould at first had lived upon the casein and lactose of the butter; when these were exhausted, it hydrolyzed the fat, consumed the glycerol and possibly oxidized part of the volatile acids to water and carbon dioxide. A small amount of aldehydes was also formed, probably by oxidation of the oleic acid.

Each of the following moulds was sown in pure culture upon ordinary butter, and was allowed to act for three months: *Aspergillus glaucus, Aspergillus niger, Botrytis cinerea, Eurotium repens, Mucor mucedo, Mucor racemosus, Mucor stolonifer, Penicillium glaucum, Verticillium glaucum.* The butter had not been sterilized, and *Oidium lactis* developed upon the samples as well as upon the control. The most striking change produced by the moulds was the great increase in the acid value of the butter fat. *Verticillium glaucum* produced a mouldy odor; *Mucor racemosus* gave the butter a greenish-yellow color, due to the mycelia. *Mucor mucedo* thrived best and was chosen for a further experiment; this mould was sown in pure culture upon ordinary (not sterile) butter, which was spread out in a thin layer on glass dishes and was stored for one year in a dark, moist place. A control experiment was made avoiding infection. In both the experiment proper and the control *Oidium lactis* developed.

Mucor mucedo had developed at the end of the year to such an extent that the white of the mycelia replaced the normal color of the butter. The molten butter fat was a dirty yellow and had a not very repulsive taste. From the constants previously determined, it was seen that the most marked change was the hydrolysis of the fat into free fatty acid and glycerol. The

other change is in all probability an oxidation of the lower fatty acids, although reduction of these acids is not excluded. The quantity of volatile fatty acids fell, but their mean molecular weight rose, hence the mould destroyed the lower of the volatile acids; this destruction of lower volatile acids accounts for the lower saponification number of the fat. The quantity of unsaturated fatty acids changed but little, for the iodine number showed only a very slight decrease. A slight quantity of aldehydes was formed, from the oleic acid or from the glycerol, or by reduction of the lower fatty acids. The control, in which *Oidium lactis* developed, showed similar, but not such extensive, changes. The conclusion is reached that the moulds consume the protein and lactose, then very actively secrete lipolytic enzymes. The enzymes split the butter fat and place the glycerol thus produced at the disposal of the moulds for food. Of the fatty acids, formed by the hydrolysis, apparently only those of lower molecular weight are assimilated by the moulds.

While Hanus and Stocky were working with moulds, Reinmann [14] was studying the effect of bacteria, moulds and yeasts upon both ordinary and sterile cream butter. Following the procedure of Amthor, he obtained from rancid butter a distillate which had a not unpleasant odor chiefly recalling that of butyl butyrate. Other distillates possessed a different odor and a higher acidity. Reinmann agrees with Amthor [11] that the smell and taste of a rancid butter are due to ester-like bodies. He declares the odor is the only direct measure of rancidity; since in a butter the changes are accompanied by liberation of fatty acids, a comparison of samples but not an actual determination of rancidity may be made by means of the acid value of the butter-fat.

The influence of the chemical composition of the butter upon the development of rancidity was also studied. Three butters were made from raw cream; the first was prepared with as high a casein and lactose content as possible; the second was rendered as free as possible of buttermilk by working; the third was washed with water until the latter could be decanted perfectly clear. A butter with high casein and lactose content was also made from sterile cream. All four samples were exposed to the air and light of the room at 16–19° C. for a period of six weeks. All the butter prepared from raw cream became rancid and showed a progressive increase in the free acid content; the butter

with high percentage of casein and lactose was the first to become rancid, and also showed the highest acidity. The butter which had been churned from sterile cream, remained good and free from rancidity after it had been kept four months; its acidity had increased very slightly. These experiments indicate that rancidity of butter cannot be due to a high casein or lactose content or to mere oxidation, but must be caused by either micro-organisms or enzymes.

Samples of butter were kept for a period of seven weeks exposed to air and light, to air without light, to light without air, and with the exclusion of both air and light. Air was excluded by storage of the samples in an atmosphere of hydrogen beneath bell jars; alkaline pyrogallol was placed in the jars to absorb traces of oxygen. When air had access to the butter, both in the dark and in the light, rancidity and a considerable increase in the acidity occurred. When air was excluded both in the dark and in the light, the acidity rose slightly, but the butter was still good, though somewhat altered. From these experiments, it may be concluded that anaerobes scarcely play a rôle in the production of rancidity. The air does play a part, in all probability through strictly aerobic micro-organisms.

In the following experiments on the influence of antiseptics, control experiments were made using butter without any added material. Sodium chloride retarded both rancidity and acidity; 6 per cent. sodium chloride possessed a greater retarding influence than did 1 per cent. sodium chloride. Salicylic acid prevented rancidity and acidity.

A sterile butter was made from sterile cream in sterile vessels and worked with sterile instruments. It did not become rancid when exposed to air and light. Nevertheless, when this sterile butter was infected by means of a small quantity of rancid butter, rancidity then developed. The results obtained by the action of antiseptics and by innoculation with rancid butter, tend to exclude atmospheric oxygen as the direct cause of rancidity, and to substitute either enzymes or micro-organisms.

Ordinary and sterile cream butter samples were inoculated with a pure culture of each of the following organisms: *Micrococcus acidi lactici, Sarcina lutea, Bacillus acidi lactici, Bacterium helvolum, Bacillus coli communis,* a coli-like bacillus (strawberry bacillus), *Bacillus mesentericus vulgatus, Bacillus butyricus*

Hueppe, *Bacillus butyricus* Botkin, Bacillus *fluorescens liquefaciens, Bacillus proteus mirabilis, Streptothrix alba, Oidium lactis,* a white yeast, a rose yeast, a mucor fungus, and another yeast, a " Sprosspilz."

Control experiments were made with both non-inoculated butters, the ordinary butter, and the sterile-cream butter. None of the organisms were able to render butter rancid. In the case of the common butter, the inoculated samples and the control behaved alike, for all became rancid. Three species, *Bacillus fluorescens liquefaciens, Streptothrix alba* and the " Sprosspilz " made the sterile-cream butter strongly acid, and gave it a highly offensive odor, but failed to produce rancidity. On the other hand the coli-like bacillus produced an aroma of strawberries, and the mucor fungus an odor of oil of bitter almonds, both very pleasing to the sense of smell. Although these samples became acid, they had a very agreeable taste.

When sterile-cream butter was inoculated with the mixtures of bacteria derived from butter, milk, cream, earth, dust and water, rancidity failed to develop. In one case the bacteria of cream produced a slight rancidity. However, inoculation with rancid butter caused rancidity to develop in the sterile-cream butter. Reinmann concludes that either organisms, which have escaped his culture method, or enzymes are the cause of rancidity. He considers the retardation of rancidity by sodium chloride as an argument against enzymes.

Jensen [15] made an exhaustive study of the flora of butter, with special reference to the development of rancidity. The results of his labors are contained in a series of thirteen papers. He found that under the same conditions sterile butter underwent a more intense oxidation, *i.e.*, greater decrease in iodine number than did common butter. The ordinary butter, however, showed higher acid values and a stronger odor of rancidity. The explanation is given that the organisms commonly present in butter prevent the oxidation of the butter; the oxygen merely accelerates the development of those organisms which produce rancidity. Butter stored without air access became acid and possessed a cheese-like taste, but did not become rancid. Jensen gives three facts in support of the theory that aerobic organisms and not milk enzymes are the cause of rancidity. First, salt—which inhibits the action of organisms far more strongly than it does

the action of enzymes—retards rancidity. Second, a high content in lactose and casein, which form a supply of food for organisms but are not of benefit to enzymes, accelerates rancidity. Third, complete exclusion of air prevents rancidity.

As butter grew rancid, Jensen noticed that it darkened somewhat and became transparent from the surface toward the interior. The clearing or transparency he attributed to the solution and decomposition of the casein by the organisms of the surface. Of these surface organisms, *Bacillus fluorescens liquefaciens* and occasionally *Bacillus prodigiosus* increased for a time; finally *Oidium lactis, Cladosporium butyri* and yeasts in spite of their slow increase overgrew the other organisms and formed the surface-vegetation.

Within the butter various lactic acid forming bacteria and yeasts increased, then decreased. Liquifiers and *Oidium lactis* always decreased. At times *Micrococcus acidi lactici* showed a slight increase.

The following table shows the organisms which were found in butter by Jensen:

	Fresh butter	Rancid butter
Microörganisms which always occur.	*Bacterium lactis acidi* (Leichmann) and other lactic acid ferments.	*Oidium lactis.*
	Varieties of *Bacillus aerogenes.*	*Cladosporium butyri.*
	Bacilli similar to aerogenes, probably *Bacillus innocuus* (Wilde).	*Mycoderma species.*
	Micrococcus acidi lactici (Krüger).	Lactose-fermenting yeasts.
	Bacillus fluorescens liquefaciens.	Lactic acid bacilli. (*Bacillus a* (Freudenreich) and similar forms).
Microörganisms which frequently occur.	The organisms always found in rancid butter.	The organisms always and frequently found in fresh butter.
	Bacillus prodigiosus.	*Bacillus microbutyricus* (Hellström).
	Bacillus microbutyricus liquefaciens.	*Penicillium glaucum.*
Microörganisms which rarely occur.	Non-liquefying proteus species (Proteus Zopfii and Proteus Zenkeri).	
	Coli species.	
	Hay bacilli.	
	Bacillus fluorescens non-liquefaciens	
	Streptothrix alba.	
	Streptothrix chromogena.	

The influence of each of these organisms, or of mixtures of the organisms upon sterile butter, was studied by inoculating into sterile cream which was placed in the glass vat of a butter machine and churned in the usual way. When the buttermilk was decanted, the opening of the churn was covered with a recently ignited wire gauze. The washing of the butter was done with sterile water, which was decanted in the same manner. The butter was then transferred to a sterile glass jar, the neck of which fitted into the neck of the churn. The jar, like the churn, was closed with a sterile stopper and was agitated to collect the butter into a lump. Such butter has a normal water content. When the influence of lactose or of salt was studied, a 5 per cent. sterile solution of the former, or a 25 per cent. sterile solution of the latter, was used for washing the butter. The samples were stored in the dark at room temperature for two months.

Non-liquefying bacteria, including *Bacterium lactis acidi*, *Bacillus* [a], *Bacillus aerogenes*, bacilli similar to aerogenes, and mixture of *Proteus Zopfii*, *Proteus Zenkeri* and a stench-producing coli species, were found either to lack the fat-splitting power or to possess this power to so slight a degree as scarcely to play a part in the rancidity of butter. *Bacillus fluorescens non-liquefaciens* and *Bacillus coli communis* probably have the power to hydrolyze fats and to produce rancidity but, on account of their rare occurrence in butter, were not investigated.

The influence of liquefiers was also investigated. *Bacillus fluorescens liquefaciens* hydrolyzed the butter fat with the production of large quantities of volatile fatty acid. The organism splits the glycerides uniformly; but, when it consumes the liberated fatty acids, prefers the non-volatile acids. The butter became rancid; the odor was that of free butyric acid and not that of its ethyl ester. When a sterile butter was inoculated with a mixture of *Bacillus fluorescens liquefaciens* (to produce butyric acid) and a lactose-fermenting yeast which occurs in butter (to produce alcohol), no ethyl butyrate was formed. This experiment tends to overthrow the hypothesis of Amthor [11] concerning the formation of butyric ester in rancid butter. *Bacillus fluorescens liquefaciens* and *Bacterium lactis acidi* usually occur together in butter, therefore a butter containing a mixture of the two organisms was prepared. The lactic acid formed by *Bacterium*

lactis acidi exerted a retarding influence upon the fat-splitting property of *Bacillus fluorescens liquefaciens*. The presence of salt in butter retarded both the increase of *Bacillus fluorescens liquefaciens* and the hydrolysis of the butter-fat.

Bacillus prodigiosus split the butter-fat with the liberation of both volatile and non-volatile fatty acids. The rancid odor was more disagreeable than was the odor produced by *Bacillus fluorescens liquefaciens*.

Bacillus microbutyricus liquefaciens caused but a slight hydrolysis of the butter fat; the taste and smell of the butter remained unchanged.

Hay bacilli produced no change within the butter; they rendered the surface transparent and gave it a rather unpleasant taste, but failed to cause rancidity. They were especially sensitive to lactic acid, and soon died off when lactic acid formers were present.

Streptothrix chromogena was chosen as the representative of the *Streptothrices*, which in certain respects mark the transition from bacteria to moulds. It hydrolyzed the butter fat somewhat and, after acting for one week, had produced so unpleasant an earthy odor as to render the butter unfit for use.

Three lactose-fermenting yeasts, which differ in mode of spore-formation, occur in butter. None of the three yeasts was able to decompose butter fat or to produce any apparent change in butter. A slight quantity of alcohol was formed.

A maltose-fermenting *Mycoderma*, which occurs frequently in butter, was found to lack the power to hydrolyze butter fat. The butter had a faint ester-like odor upon its surface; but esters could not be detected quantitatively. This yeast thrived best upon the surface of the butter, hence was aerobic.

Oidium lactis, a mould, not only hydrolyzed the butter fat but also peptonized and further decomposed the casein with the formation of basic compounds. Within the butter the liberated volatile fatty acids were neutralized by these basic compounds; upon the surface both free volatile acids and glycerol were consumed by the mould. When lactose was added to the butter, *Oidium* both split the butter fat and fermented the milk-sugar to alcohol; however, no ester was formed. The presence of salt in butter retarded the growth of the mould and also the hydrolysis of the butter fat. The influence of mixtures of *Oidium* and

organisms, which in themselves do not attack butter fat, upon sterile butter was also studied. The lactic acid formers prevented for a time the rancidity of the butter. Jensen suggests that *Oidium lactis* before splitting the butter fat either consumed part of the lactic acid or produced ammonia from the protein in order to neutralize the lactic acid. *Micrococcus acidi lactici* and *Bacillus microbutyricus liquefaciens* were killed by free fatty acid.

A mixture of *Oidium lactis* and either *Bacillus fluorescens liquefaciens* or *Bacillus prodigiosus*, both of which hydrolyze fat, set free a far greater quantity of fatty acids than was produced by either of the organisms by itself. The *Oidium* was able to reduce considerably the quantity of free volatile fatty acids liberated by the bacilli.

Cladosporium butyri, another mould, produced green and brown veins upon the butter, which darkened somewhat. *Cladosporium butyri* did not split the butter fat to such an extent as did *Oidium lactis*, but like the latter it consumed the liberated volatile acids. A distinct odor of ethyl butyrate was observed, hence probably this mould was present in Amthor's butter. *Cladosporium butyri* did not produce the ester-odor in a butter to which lactose had been added; hence the ethyl butyrate did not derive its alcohol radical from the lactose content of the butter. According to Jensen, the butyric ester is an intermediate product in the decomposition of the fat by the mould. Tributyrin is decomposed with the formation of ethyl butyrate, the ethyl group of which is derived from the glyceryl radical of the tributyrin. The ethyl butyrate undergoes further decomposition. When *Cladosporium butyri* was allowed to act upon tributyrin, a distinct odor of ethyl butyrate was produced. Therefore, this mould possesses, in addition to the hydrolytic power, the property of attacking the combined glycerol of fats with the production of esters. *Cladosporium butyri* prefers lactose to combined glycerol, hence no ester was formed when lactose was added to the butter in the experiment described above. This mould may produce the odor of amyl butyrate in butter; it forms little ammonia from the butter proteins.

A mixture of *Cladosporium butyri* and *Bacillus fluorescens liquefaciens* produced the same changes as did the former by itself; the mould caused the bacillus to decrease. Inoculation of butter with both *Oidium lactis* and *Cladosporium butyri* gave

rise to a quantity of free fatty acid which exceeded the sum of the quantities liberated by each mould acting independently; the butter was highly rancid, contained large amounts of both solid and volatile free fatty acids, and smelt strongly of ethyl butyrate. Addition of lactose did not prevent ester formation in this case.

Cladosporium butyri was able to live in a butter in the presence of such a quantity of free volatile acids as would kill *Oidium lactis.*

Penicillium glaucum formed dark green veins upon the surface of the butter. The surface tasted musty and acid; the interior acid and bitter-sweet. The mould possessed exactly the same hydrolytic power as *Oidium lactis,* consumed the free fatty acids on the surface, and produced amyl butyrate and possibly ethyl butyrate; it formed little ammonia.

A mixture of *Penicillium glaucum* and *Oidium lactis* produced an aroma of Roquefort cheese, due possibly to the odor of ammonium salts of volatile fatty acids combined with that of esters, particularly amyl butyrate. *Penicillium glaucum* formed the esters, while *Oidium lactis* by virtue of its proteolytic power furnished ammonia to neutralize the free volatile acids.

Jensen divides those organisms which decompose butter fat into three classes. The members of the first class are able to hydrolyze fat but lack the power to attack combined glycerol, hence they only form free fatty acids; *Bacillus fluorescens liquefaciens, Bacillus prodigiosus* and *Oidium lactis* are representatives of this class. The second class includes organisms which not only split fat with the production of free acids, but also consume the combined glycerol with the formation of esters; these esters are further decomposed; *Cladosporium butyri* and *Penicillium glaucum* may be considered types of this group. The third class consists of organisms which do not hydrolyze fat but only attack the combined glycerol with the formation of esters; certain *Mycoderma* species belong to this class.

Jensen demonstrated the presence of a lipolytic enzyme in *Bacillus fluorescens liquefaciens* and in *Oidium lactis.* The culture of each organism was ground carefully and was filtered through a Chamberland filter. The filtrate was shaken with sterile, half-molten butter, while the container was cooled by means of ice water. The portion of the aqueous extract of the organism, which was not retained by the solidified butter, was

decanted. In the case of each extract the butter remained sterile; but its acid value increased, although the acidity of a control butter did not change. Since all fat-splitting organisms hydrolyze the different glycerides of the butter fat in the same ratio, it follows that each glyceride does not require a special lipolytic enzyme.

Jensen concludes that rancidity of butter is due to the presence of volatile fatty acids and esters. The bacteria liberate volatile fatty acids during the earlier stages of the process; later on, the moulds, especially *Oidium lactis* and *Cladosporium butyri*, by their combined action give rise to both volatile acids and esters.

Lafar [16] suggests that the normal aroma of butter is due partly to the action of *Bacillus butyri fluorescens*. He also stored a sample of butter and a specimen of the same butter, to which 10 per cent. of sucrose had been added, in an atmosphere of hydrogen for 37 days. At the end of the period both samples retained their pleasant taste; no rancid or unpleasant odor had developed; the color, however, had become somewhat paler. *Bacterium butyri colloideum* was the predominant species in these stored butters. From the bacterial content of the two samples, and from the absence of rancidity in them, Lafar concluded that certain bacteria are able to thrive in butter even when air is excluded, but an influence upon the rancidity of butter is not to be ascribed to these organisms. Moreover, the presence in butter of aerobes, which are able to increase in a medium containing sugar even when air is excluded, could not be shown.

Conn [17] and Weigmann [18] agree that the aroma of sweet butter is due to the simultaneous action of several species of micro-organisms. Conn states that the good flavor is produced by acid formers, and good aroma results from the action of other micro-organisms. He mentions two species which gave to butter an aroma very closely approximating to, if not identical with, the aroma of normal butter. Under cultivation these species apparently lost their aroma-producing power; they were not acid formers, but rather belonged to the class of organisms that attack albumen. The flavor which they produced in butter was inappreciable. Weigmann concludes that the aroma of ordinary commercial butter is due to the action of two classes of organisms. The one class possesses the property of acid-formation and ester-formation, while the other class is characterized by

proteolytic power. Compounds which have a good odor and taste are thus produced.

Laxa [19] studied the effect of each of the following organisms upon butter fat: *Oidium lactis, Penicillium glaucum, Mucor, Saccharomyces, Tyrotrix tenuis,* another *Tyrotrix* species, *Bacillus fluorescens liquefaciens, Bacilli* numbered 2 and 3, *Bacillus a Freudenreich,* a streptococcus and a sarcina. Laxa used a unique process in order to obtain a medium which contained butter fat in a fine state of division. Milk was treated with rennet, the curd was collected and sterilized by means of steam. Lactic acid had previously been added to the curd intended for use with moulds and yeasts. Each organism was sown in pure culture upon this medium; the inoculated curds were stored in a dark place at room temperature for a period of one to four months. At the end of that time, analyses were made of the fat of those curds each of which was found to be a pure culture of the particular organism with which it was inoculated. Contaminated curds were rejected. The fat of sterile control curds was submitted to analysis at the same time. To separate the fat from the curd, the latter was acidified with dilute sulphuric acid and extracted with ether. The fat, which remained after evaporation of the ether, was washed with warm water until free from sulphuric acid, and then was filtered and dried at 100° C.

Both *Mucor* and *Oidium lactis* increased the iodine number and acidity of the fat, and decreased the refractive index, saponification number and Reichert-Meissl number. *Oidium* caused an increase in the Hehner number. The mean molecular weight of the volatile fatty acids was increased by each of the moulds. Both moulds liberated insoluble fatty acids the mean molecular weight of which was higher than that of the insoluble acids of the control; hence, the conclusion is drawn that hydrolysis of the glycerides of all the insoluble acids does not occur uniformly, but the glycerides of the insoluble acids of higher molecular weight are more readily attacked. The iodine number of the insoluble acids liberated by *Oidium lactis* was higher than that of the insoluble acids of its control, while those liberated by *Mucor* had an iodine number very slightly lower than that of the insoluble acids of its control.

Penicillium glaucum gave rise to an increase in the acidity of

the fat, and produced very slight decreases in the iodine and Reichert-Meissl numbers.

Each of the moulds, *Oidium lactis, Mucor,* and *Penicillium glaucum,* was allowed to act in pure culture upon a nutrient solution to which a small, known quantity of one of the acids—acetic, butyric, caproic, and caprylic—had been added. After seventeen days had passed, the residual acid was determined in each experiment by acidifying with dilute sulphuric acid, distilling, and titrating the distillate. *Oidium lactis* was able to consume acetic butyric and caproic acids; *Penicillium glaucum* consumed acetic and butyric acids and traces of caproic acid; *Mucor* consumed acetic acid. None of the moulds was able to decompose caprylic acid, which prevents their growth; even its lower homologues, if present in sufficient concentration, exert an influence harmful to the growth of the moulds. Since these higher volatile, soluble acids in the free state act as poisons toward the moulds, hydrolysis of the glycerides of the volatile acids decreases as their molecular weight increases.

In a nutrient solution, to which 1 per cent. glycerol had been added, *Oidium lactis* completely consumed the glycerol during the course of a month.

Laxa proved the existence of a lipolytic enzyme secreted by *Penicillium glaucum* and by *Mucor.* The pellicle obtained by growing one of these moulds, was ground with glass and the resulting liquid was filtered through fine-meshed linen. The liquid from each mould was able to hydrolyze both monobutyrin and butter fat. Either totuol or chloroform was used as a bactericide. Similar experiments with *Oidium lactis* gave such unsatisfactory results that no conclusions could be drawn concerning the secretion of a lipase by this mould.

It was proved that, when either *Oidium lactis* or *Penicillium glaucum* act upon casein in the presence of a solution of mineral salts and lactic acid, fatty bodies are formed from the casein and may be isolated from both the mould pellicle and the liquid. This fat, which has an iodine number far higher than that of butter fat, however, is produced in such minute quantities that it can exert no influence upon the constants of a fat which has been decomposed by moulds in the presence of casein.

Saccharomyces produced an odor of volatile acids. The yeast caused these changes in the constants of the fat: slight rise in

acidity, slight decrease of saponification number, exceedingly small increase of iodine number and very slight decrease of Reichert-Meissl number.

Of the bacteria which peptonize casein, each of the two varieties of *Tyrotrix* were without action on butter fat; the bacilli numbered 2 and 3 were characterized chiefly by the increase in acidity which they produced. *Bacillus fluorescens liquefaciens* gave rise to changes in the fat exactly similar to those produced by the moulds. The refractive index, saponification number and Reichert-Meissl number decreased, while the acidity, iodine number and Hehner number increased.

The lactic acid organisms including *Bacillus* [α] Freundenreich, a streptococcus and a sarcina, were without action upon butter fat.

Schreiber [20] studied the rôle of organisms in the decomposition of the fats. The organisms were allowed to act upon oil of sweet almonds which either was mixed with a nutrient solution, or was emulsified by means of gum Arabic with the nutrient solution. Pure, precipitated calcium carbonate was always added to the media for bacteria, and was frequently added to that for moulds. Two bacilli and a mould, which destroy fat, were obtained from earth by means of rolls of sterile butter fat which were buried in earth, in flower pots, for several months. At the end of that period organisms were found only on the outer portion of the butter fat; none was present in the interior. Even when a roll of butter fat was buried for a year and had become crumbly, portions of the interior were still sterile.

Each organism was permitted to act upon a known weight of almond oil, usually for 44 days at room temperature, the quantity of fat plus free fatty acid and, at times, of fatty acids present as soaps, was then determined.

Bacillus fluorescens liquefaciens was obtained from earth by means of the buried butter fat, on which it occurred more frequently than any other organism. It decomposed the almond oil vigorously; the decomposition was more rapid and extensive in emulsions of the oil in the medium than in mere mixtures of oil and medium. The bacillus died off in the incubator and in the direct sunlight without decomposing the oil. Cultivation upon artificial media caused the organism to lose its power to decompose fats.

Bacillus pyogenes was able to decompose the almond oil, but lost this power when cultivated upon artificial media. The question of the identity of this bacillus with *Bacillus fluorescens liquefaciens* has not yet been finally settled, according to Schreiber.

Bacillus ζ, which was obtained from earth by means of butter fat, not only decomposed the oil but also consumed large quantities of it. The organism was a liquefier, and retained the power to decompose fats when grown upon artificial media. It was but slightly retarded in its action upon the oil by light, but was killed by the temperature of the incubator before it could attack the oil. Both *Bacillus fluorescens liquefaciens* and *Bacillus* ζ produced butyric acid from almond oil. *Spirillum Finkler* and *Micrococcus tetragenus* also decomposed fat.

A mould designated π *Mucor mucedo, Penicillium glaucum* and an *Oidium* (either *lactis* or *albicans*) were found to possess the power to decompose almond oil. Two species of yeasts were unable to attack the oil. Moulds were not harmed by the liberated acids.

The secretion of a lipase by *Mucor mucedo* or by *Bacillus fluorescens* could not be proved, Each organism was grown in a nutrient solution for two months, and was then killed by addition of thymol. Almond oil was next added to each culture, but both qualitative and quantitative tests failed to show any hydrolysis of the oil, whence the conclusion was drawn that lipolytic enzymes had not been secreted by the organisms.

The influence of anaerobic conditions upon decomposition of fats by organisms was also studied. A nutrient solution, to which almond oil had been added, was inoculated with garden earth and preserved in an atmosphere of hydrogen for forty-four days. A very slight hydrolysis of the oil occurred, but none of it was consumed. A similar experiment, in which humus was substituted for earth, gave similar results. Schreiber is not sure that the slight hydrolysis was due to the action of organisms, but is certain that oxygen is essential for decomposition (destruction) of the fats by organisms. He also concludes that pure fat by itself does not support the growth of organisms, that organisms not only split but also further destroy fats, and that fat-destroying activity of the organisms is united with their vital processes.

Rahn [21] discusses the work of various investigators concern-

ing the changes produced by bacteria, moulds and yeasts, in butter fat during the development of rancidity; in cheese fat during the process of ripening, and in fats placed within the ground. From their labors he concludes that only a few bacteria are known which can consume fat, although in the case of the moulds this property occurs more frequently. The decomposition of fats by organisms takes place only in the presence of organic nitrogenous compounds which provide nourishment for the organisms; the glycerol of the fats also serves as a food. The decomposed fats always show a higher acid value than the same fats in the fresh condition. While bacteria, as a rule, consume the fatty acids uniformly and without choice, moulds, on the other hand, show a preference for the lower fatty acids. In the oxidation of these bodies residual products are never observed, therefore the oxidation apparently is complete. However, in the decomposition of olein, the odor of butyric acid was noticed; this acid may possibly have arisen from the glycerol or from the peptone. Rahn states that anaerobic decomposition of fats never occurs; although glycerol may be decomposed by anaerobes, this class of organisms is not able to attack the fatty acids with their low oxygen content. He ascribes rancidity to the action of aerobic organisms.

In a second paper Rahn [22] describes two bacteria, several moulds and a yeast, which were isolated by an accumulation process and special culture methods from a mixture of earth, water and palm oil or swine fat, or from an emulsion of rancid butter fat in mineral salt solution. The most prominent characteristic of these organisms was their ability to grow and to decompose fat in a medium which consisted of a solution of mineral salts. Unlike the fat-decomposing organisms previously known, these new species did not require organic nitrogenous compounds as food; an ammonium phosphate sufficed as the source of nitrogen.

(*To be continued.*)

FRANKLIN INSTITUTE

(Stated meeting, held Wednesday, April 21, 1909.)

EVOLUTION IN DESIGN, MANUFACTURE, AND USES OF TYPEWRITING MACHINES.

CHARLES D. RICE, M.E.

About the year 1867 Mr Thomas Hall had the distinction of having invented and constructed a writing machine embodying the type bar principle, which, though crude, contained most of the essentials of the successful writing machines of to-day. But it seems that he abandoned that plan of construction and devoted his energies to a machine which was finally marketed about the year 1880, known as the Hall typewriter, its construction consisting of what is known as the pantograph principle, all of the type being placed on a soft rubber pad about square in outline, so that by the moving of a stylus the proper character is brought under a recess in the plate which lies just above it, permitting this elastic type carrier to act with the proper type through the recess and with the aid of a pushing member. It was strictly a one hand machine, so far as effective work was concerned, the other hand serving as a controlling medium, and, taking into consideration this handicap, the machine served in some cases very well for that period.

The first machine introduced and which could be classed as highly practical was the Remington typewriter, possessing the now well-known type bar principle, which was first introduced about the year 1873. This machine was mainly invented by a man named Sholes, who was a printer by trade. Through the assistance of an ingenious workman, Mr. Sholes having no mechanical training, he was enabled to build a crude model machine. This proved to possess the more essential principles necessary to the class of typewriter which could best be constructed at that period. The results of his efforts were recognized as of particular merit by two gentlemen, Messrs. Densmore and Yost, long since deceased. They purchased his patents and were finally successful in interesting the Remington Company, at Ilion, N. Y., a concern which was extensively engaged in

the constructing of fire arms during the Civil War period, a class of work requiring a high degree of mechanical skill for that time.

However, the original model (which was very largely constructed from wood) was used as a masterpiece, and from it, through the skill at the command of the Remington concern, was produced a machine which would write acceptably to those having the matter in hand.

The next important problem which confronted the promotors was to establish a market and it has been related that, at first, in no particular instance could a business man be found who would believe that its introduction in the office would be a practical undertaking. They therefore adopted the policy of lending a machine to each of several hundred business houses, presumably with the hope that some would find time to practice upon them, and with the full belief that it would develop in the minds of not a few that a saving of time as against hand writing was possible.

In this their judgment proved correct, it having been reported by many that the use of the machine was not only a saving of labor in correspondence, but that it also proved of great value in the reading of letters received. It goes without saying that the more progressive of these managements quite readily adopted the typewriter thereafter.

Sufficient years have elapsed since these earliest efforts to enable those who have had many and varied dealings with the subject to judge why certain ideas in construction then prevailed. It can well be said that, at that time, to create a mechanical instrument which would possess all of the movements necessary to the writing of letters and to build it economically, could be rated as a considerable undertaking, even though certain sacrifices as regarded the user were allowed in order to favor the problem from a manufacturing viewpoint; and it is my opinion that the blind, under-strike machine, as constructed during its earlier stages, represented, and necessarily so, one of the simplest forms which could have been introduced into a factory as a manufacturing proposition and at the same time possessed elements of fair speed and durability.

In this early machine the type bars were suspended in a circle, each and all so arranged as to strike upwardly to a common centre. The key levers represented levers of the second order,

simply extending from the key button, rearward, and hinged at the back of the machine. There were wire connections between each bar and its companion lever, which were fitted with a so-called turn-buckle. This turn-buckle rendered it an easy task to establish a proper distance between the two members, the type bar and the key lever, irrespective of the position at each engaging point, as the type bars, when inactive, rested upon a central ring or nest which served to arrest their movement when returning from the printing point. The spread of keyboard and lever system, as against the diameter of type bar suspension ring, was also worthy of note. These turn-buckles, furthermore, served the purpose under adjustment to compensate for angularity of connection as well as to place each key button at its proper elevation, so as to afford an accurate level for all throughout each bank of keys.

It will be seen that, aside from the question of affording a proper and accurate jointage or hinge for each type bar, so as to insure truth of movement to the printing point, the rest of the type bar and key lever system required no great degree of exacting workmanship; and that in order to lend these important advantages to their manufacture, one of the most essential qualities from the user's standpoint—visibility—was sacrificed. The rest of the mechanism simply afforded the usual means of controlling the paper, both as to longitudinal movement and proper graduating between lines, coupled with the simplest provision for inking the type. As speed competitions between instruments was then unknown, and as the operators of these machines were, in the main, moderate in their speed of writing, refinements in detail as associated with the carriage movement were not then of a pressing nature in order to secure commercial success.

The success of this first practical writing machine during the few years which followed naturally stimulated invention, and it was but natural that other plans of construction should develop, and of course each inventor had his own notions as to the foundation principles.

A machine known as the Caligraph was one of the next to appear, the main novelty in construction being that each type bar carried but one type as against two in its predecessor, but this step doubled the number of type bars, key levers, and key buttons. Yet to offset this seeming disadvantage with the keyboard, there

was no need for a shift key in the using of capital letters. However, it seems that certain patents then still in force compelled other deviations. The lever system was extended forward and considerably beyond the keyboard, at which forward point the key levers were fulcrumed, thereby providing a lever of the third order, which principle of lever, as applied, compelled a greater variation in key depression with each key bank in order to drive the type bar to the printing point. The means for propelling the carriage longitudinally was also of a different nature, yet the carriage proper was somewhat simplified due to the absence of the shift movement. This make of machine was afterward sold in considerable numbers for a term of years. Yet as a great majority of users favored the single shift key principle, the Caligraph machine afterward became less popular and is now no longer manufactured.

Another machine which appeared soon afterward was a type wheel machine known as the Hammond typewriter, invented by Mr. James B. Hammond, who undertook the task about the year 1876, and the machine was introduced in the market, I believe, about the year 1884. This machine met with considerable success, having certain unique advantages in its adaptability to the employment of characters common to various languages, as it was provided with an interchangeable type wheel system, thereby enabling its users to quickly shift from one class of correspondence to another. I understand it is received with particular favor in the Latin countries.

As a rule, the unusual accomplishments attending any given case, that is, an arrangement which is *too* universal, are effected through sacrifice of some sort, and against the type wheel style of construction it has been claimed that the machines operate more slowly, due to the added weight of the active printing parts; for instead of acting upon an individual type bar, as with the other class of machine, a member carrying all characters is involved under this plan of construction and the added weight must necessarily retard the speed of the action.

It will be noted that prior to the year 1890 three distinct classes of machines had been developed and extensively used, and it can truly be said that very much the greater number sold of the three was that incorporating the type bar idea and with a single shift keyboard, each bar carrying two type—upper and lower case. This most popular construction, however, still

lacked a vital quality, namely, visibility, and as the typewriter business was rapidly increasing in volume it was but natural that inventors should try to overcome this defect and so endeavor to reduce the improvement broadly to commercial practice.

In this undertaking many minds were at work, the earlier attempts being largely confined to the so-called top-strike principle, which construction, due to the law of gravitation, placed the type bars at a great disadvantage in their return movement, and furthermore introduced many complications difficult to deal with in factory practice. It fell to the lot of an inventor named Franz Wagner, a German by birth, to present a foundation plan of the construction for a visible writing machine and, with the aid of other able minds, this developed into what afterward became known as the Underwood visible typewriter. This machine incorporated a front-strike principle of type bar, and was first introduced into the market in a very limited way in the year 1896.

The advantages of the front-strike principle in visible writing machines may be set forth as follows: The type bar moves downward from the printing point after printing, thus affording a quick return to the bar, particularly with a provision on the Underwood of the so-called banking ring. Against this banking ring each type bar collides about midway in its length in printing, thereby affording a quick reacting movement, lending speed to the machine by aiding in the prevention of type bar collisions, this banking ring also helps to quickly separate the type from the paper after the imprint is made and thus prevents a blur, as with a speedy up-to-date machine the carriage movement starts simultaneously with the contact of the type. While it is true that in starting the type bar in action toward the printing point it immediately begins with an upward movement, yet this seeming disadvantage is very cleverly overcome by means of a cam action associated with the bar, whereby the greatest leverage is had in starting the bar into motion; the cam movement so favoring the motion thereafter as to lend an accelerated action, giving quickness of movement as a whole and yet an easy starting action under finger pressure at the key lever. The front-strike idea also places the printing-point at the best position and favorable to the operator. It also makes possible in the construction of the machine a proper position for parts such as would otherwise detract from this valued quality.

That the perfecting of a front-strike visible machine, such as was introduced as far back as the year 1896, was a great step of progress, can best be judged by the number of similar machines incorporating this principle which have since been introduced by several of the most prominent of the older makers of typewriters.

The building of typewriters, cash registers, adding machines, sewing machines, small fire arms, bicycles, etc., comes within the scope of what is known as manufacturing on the interchangeable part plan, the sewing machine presumably being one of the first inventions wherein this system was applied in a broad sense. This system was developed almost wholly in New England, and principally in the State of Connecticut, as was also the case with the sewing machine itself. Associated with this system of manufacture are several machines, which were necessarily perfected to give the plan completeness and economy of method. While this group of machines is at present extensively used throughout the civilized world, giving wonderful productive power, New England contributed: the milling machine, punch press, drop hammer, high speed sensitive drilling machinery, and the profiling machine, the latter so largely used in fire arm manufacture on irregular forms of the compounded type.

Coupled with the above as manufacturing machines, followed the special tools, such as jigs for the establishing of holes with interchangeable accuracy, punches and dies of endless variety for the shaping of sheet metals, and milling machine cutters with their many irregular forms.

The earlier typewriter, when introduced, lacked many of the manufacturing advantages common to-day, as the art of manufacturing on the interchangeable plan began substantially with the sewing machine and has been developed almost wholly within the lifetime of many now living. Very many of the instruments which have to do with interchangeable accuracy have been developed since the typewriter reached the state of common use, and it will therefore be understood why certain designs prevailed. With few exceptions precision work, owing to the nature of earlier typewriter designs, was not necessary, for, barring the jointage of the type bar in order to preserve its truth in printing, there was little required in accurate workmanship throughout the system of type bars, key levers, and connecting parts; the key levers, for example, consisting merely of plain straight bars

of wood. Therefore, perhaps, two reasons can be assigned for the appearance to start with of a machine devoid of the visible writing quality: first, because a construction yielding visibility would have proved a too difficult task to the inventor at that time; second, had such a machine, even as represented in the most up-to-date pattern of to-day, been then presented in model form, the incompleteness in manufacturing methods and practice of that period would have rendered impossible the task of its practical manufacture. Among the earlier machines the Hammond displayed certain unusual attainments in advanced workmanship, as the fashioning of steel dies or moulds for their hard rubber type wheels represented a rare acomplishment for that period.

In the way of raw materials as applied to instrument building, the progress made in the manufacture of steel in its various forms has been very great, and as similar gains have also been made in the production of other raw material, so likewise have the manufacturers of special and complete mechanisms followed in the train of mechanical progress. For instance, should a typewriter factory cease to harden all of such parts, as is the practice of to-day, and yet do all else equally well, its product would be practically valueless to the using public, although but a few years ago very few of the parts received such treatment. The result is a greatly increased life and substantial value commercially.

Assuming, therefore, that proper advancement has been made mechanically since the introduction of the typewriter, the "Factory" and its workings may be briefly considered. The plant of the Underwood Typewriter Company embodies the most modern ideas of factory management and may properly serve as a model for the general consideration of the subject.

In the operation of an extensive plant of this class, there is necessarily much applied system which includes many distinct branches of labor. Apart from those relating to production, it has been found necessary to establish an Experimental Department in which is employed a corps of trained technical men whose duty it is to find solutions to the many technical problems that arise in the course of manufacture and to devise and apply novel features or improvements demanded by the consistent growth of the art. The maintainance of a depart-

ment of this kind, though it takes no part in the operations of manufacture, has amply proved its value by its influence in effecting economies in manufacture and improving the product.

When a large plant is operating to its full capacity great care is necessary in the purchase of material, machinery and tools, that each is of the proper character and quality and delivered at the proper time. This service demands of the Purchasing Division very close contact with the workings of the factory as well as an accurate and extended knowledge of the resources of available supply houses, as it is necessary to know what firms are best qualified to supply material in accordance with the factory's needs.

The division termed the Ways and Means Department, includes a designing department especially devoted to the consideration of problems of factory equipment and the machine shop applied to the building of special tools and special machinery and to their upkeep.

A standard design of the finished product, therefore, having been adopted and assuming that raw materials, manufacturing machinery, tools, fixtures, etc., are furnished, the next division is devoted to the manufacture of parts. Such instruments as typewriters are composed of an aggregation of distinct devices each performing a separate function and each, in itself, representing groups of parts. It is, therefore, found to be most practicable to subdivide the manufacture departmentally in group form, each department building a substantially separate group of parts. In addition to these, assembling, aligning and final inspection departments are provided.

There must be not only a perfect understanding of the requirements of each department but a harmonious co-operation between them. Indeed the productive capacity of the various departments must be so co-ordinated that at no step in the successive operations is any undue haste necessary to avoid congestion which might effect quality. In a well administered organization the rate of output of each department is so well adjusted that, for weeks in advance, the number of finished typewriters may be accurately predetermined.

The factory of the Underwood Company is one of the largest typewriter plants extant in point of floor space and number of operatives employed. Its buildings are nearly all new and of

modern mill construction. It contains about 347,500 square feet of floor space and employs nearly 2,000 operatives. Lighting and other features conducing to comfort and a resulting greater efficiency have received most careful study. Separate dining rooms for the men and women employed are maintained by the Company where a mid-day lunch may be obtained at cost. An emergency hospital is another provision for the welfare of the employees available without cost where first aid is given and wounds may be periodically dressed. A Mutual Beneficial Association is maintained by the men with the co-operation of the Company who contribute an amount equivalent to that subscribed by the members.

In harmony with the Company's endeavor to stimulate the efficiency of its men, as well as to promote their welfare, a merit-system is applied throughout the works. The leader of each department keeps a careful record of the accomplishments and progress of his operatives with a view to voluntarily affording each a fair and just compensation. These are reported and acted upon monthly. A premium system is also employed which avoids some of the defects of the commonly known piece work system. The plan of studying the welfare of the personell has proved most profitable in leading to almost uniform content and in raising the standard of efficiency of the workmen.

The subject of efficient leadership throughout the factory is a very important one, as, in this case, it involves the selection and directing of a large corps of men, each being chosen from a careful consideration of those requisite cardinal qualities,—honesty, disposition and natural ability and adaptability. It is only a close adherance to this mode of selection that will insure what may be classed as "team work" in its true sense. The so-called "team work" is the key-note to success in furnishing a product that will insure public good will, without which the growth of the project and demand for its product is not possible.

In the uses to which typewriters have been placed, there has been the same degree of advancement as in the improvment of the machine and the methods employed in its manufacture, and this has been particularly true during the last five or six years. Prior to that time, our company, which should afford a good comparison for trade wants, made but two widths of typewriter carriages, 10 in. and 14 in. respectively, the 14 in. alone represent-

ing the machine for special purposes. In response to increasing demands they are now made in seven widths, from 10 in. to 26 in.

Coupled with this great variety of widths of typewriters, there have been designed, step by step, numerous attachments to be applied to any width of carriage and for some particular class of work, such as did not apply to typewriting machines of the past. These may be enumerated as follows:

A so-called condensed billing attachment, which is meeting with so many and varied requirements with large business houses in general.

The tally strip device, which, in particular, has proved popular in department stores.

A decimal tabulator, which applies so well with insurance companies, banks, and with many other branches of work.

The universal card attachment, which facilitates the placing of a card to conform with the original printed matter contained thereon.

A label-writing attachment, adapted for the writing of labels in drug stores, as a label the size of an ordinary postage stamp can be placed under perfect control while writing.

An envelope and card inserting attachment.

A paper roll and paper knife attachment, particularly adaptable to railway work.

A typewriter-adding machine, the combination affording great advantage with certain classes of work such as is common with large manufacturers, department stores, banks, and some branches of insurance.

A back-spacing attachment, which facilitates the correcting of an error, particularly when quickly detected, as when using a visible writing machine.

Writing machines are also equipped with special type, such as would apply in the writing of life insurance policies, and also for check writing in non-erasable form.

A word regarding the growth of the typewriter business from its small beginnings may be interesting. It is estimated that in normal times about 300,000 high-grade typewriters are now produced yearly, representing a business of about $30,000,000 annually. It is also true that the United States has produced nearly all of these machines from the first, Germany alone having made any progress in this direction and only in recent years.

It is also estimated that there are between 1,600,000 and 1,800,000 writing machines in daily use; lending tremendous earning power and commercial advantage as against the old-time practice of hand writing. In fact, the art of stenography, coupled with the use of the writing machine, has given such relief to men of high position as to add much toward the world's progress.

In treating a subject so broad in its scope, I have been compelled to gather data from several directions, and I feel particularly indebted to Mr. Lee S. Burridge, the proprietor of the Sun Typewriter Company, and also to the Providence Society of Mechanical Engineers for valued assistance.

BARK AFFECTS PENETRATION OF WOOD PRESERVATIVES.

The government has gone into the study of every phase of wood preservaiton, and as progress is made in new experiments important facts are brought to light which heretofore have been given little or no attention. One of the features in the work of wood preservation which has been neglected is the effect of patches of inner bark of wood in preventing proper penetration of preservatives.

Before timber is subjected to preservative treatment, it is customary to remove the bark. Unless this is done very thoroughly, however, patches of the inner bark will remain on the wood.

Until recently, it does not seem to have been realized that this bark presented a very effectual hindrance to the penetration of creosote. In conducting some tests on the treatment of pine in Louisiana and Alabama in 1907 and 1908, it was noticed by a representative of the Forest Service that very little or no creosote entered the wood through even the thinnest layer of adhering bark.

The same thing was discovered by the management of one of the large creosoting companies in the South, and steps were immediately taken to see that every particle of bark was removed from piling and other timbers. While it is probable that the bark of all species is not as resistant as that of pine, it is not known how the different species rank in this respect.

In the creosote treatment of timbers, it is rarely that the entire stick is penetrated by the preservative. The value of the treatment consists largely in the creating of an exterior antiseptic zone around the untreated interior portion. If this outer zone be broken, the value of the treatment is to a large extent lost.

In the case of piling, the effect of any small portion of untreated wood extending from the outer surface to the interior of the pile is especially injurious because of the manner in which teredos work. The teredo enters the wood when small, making but a tiny hole, perhaps no larger than a pinhead. As they grow, they increase the size of their borings, and if present in large numbers they will very quickly so riddle and weaken a pile that it will break off with a very slight strain. Access to the interior of a treated pile might readily be gained through small untreated portions of the outer surface of the wood, which, because of bark adhering at time of treatment, absorbed no preservative, with the result that all of the interior untreated portion would be riddled, leaving only the exterior creosoted shell sound. It is probable that many of the failures of creosoted piling are due to this cause.

With other forms of timber, the effect may not be so quickly seen or so disastrous, but in a similar manner decay may extend to the interior through any untreated portions communicating with the exterior.

FRANKLIN INSTITUTE

(Proceedings of the stated meeting held Wednesday, October 20, 1909.)

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, October 20, 1909.

DR. E. GOLDSMITH, Temporary Chairman.

Additions to membership since last report, ten. The communication of the evening, entitled "Some of the Lighting Features of the Hudson-Fulton Celebration," was presented by Mr. Arthur Williams, Chief Inspector of the New York Edison Company. The speaker made a brief reference to the objects of the celebration and gave numerous interesting facts concerning the leading figures in honor of whom it was held. He then proceeded to describe the special electrical installations for the occasion and exhibited many remarkable lantern views, taken from photographs, of the night illuminations in and about New York City. A vote of thanks was tendered the speaker and the meeting adjourned.

JAMES CHRISTIE,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract from proceedings of the stated meeting held Wednesday, October 6, 1909.)

HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, October 6, 1909.

MR. J. Y. MCCONNELL in the Chair.

The following reports were presented for final action:

(No. 2432.) *Color Photography.*—Lumiere & Son. [Returned to subcommittee for certain amendments.]

(No. 2457.) *Telelectric Piano Player.*—John F. Kelly, T. P. Powers, and M. R. Jewell. [Returned to subcommittee for more detailed description.]

R.

BOOK NOTICES

ANALYSE DU CAOUTCHOUC ET DE LA GUTTA-PERCHA. Par Maurice Pontio, Lauréat de la Société Chimique de France. 170 pages, 4½ x 7½ inches, with 11 figures (Encyclopédie Scientifique des Aide-Mémoire). Gauthier-Villars, Paris, 1909. Paper, 2 francs 50; cloth, 3 francs.

The first part of this work is devoted to the study of Caoutchouc, its definition, its botanical origin and its physical and chemical properties. The second part deals with gutta-percha and treats of similar investigations of the related product.

The procedure and apparatus for physical tests and chemical analysis adapted to commercial requirements are fully set forth, and the volume, despite its small size, constitutes a comprehensive reference work on the commercial examination of these products. L. E. P.

LA THÉORIE DES COURANTS ALTERNATIFS. Par Alexandre Russell, M.A., M.I.E.E. Traduit de l'Anglais par G. Séligmann-Lui, ancien élève de l'École Polytechnique, Inspecteur général des télégraphes. Volume II; iv + 460 pages, 6 x 9 inches, 137 figures. Gauthier-Villars, Paris, 1909. Price 15 francs.

This is a complete treatise in which mathematical processes have been applied without stint in elucidating the subject. Notwithstanding this the author has borne in mind that the primary object is clearness and precision in making deductions and, accordingly, when that end can be served the mathematical elegance of general methods has been occasionally sacrificed to more direct proofs by which the real nature of the phenomena treated are less obscured than they would be if deduced from some general algebraic expression.

The theoretical elements only are treated in the first volume, applications and practice being reserved for the second volume. The treatment as a whole is unusually clear, the mathematical steps in the various deductions being explained with minute care.

A full bibliography is arranged under separate topics at the end of each chapter. L. E. P.

LA RÉFRACTOMÉTRIE ET SES APPLICATIONS PRATIQUES. Par D. Sidersky, Ingénieur-Chimiste. 172 pages, 4½ x 7½ inches, with 39 figures (Encyclopédie Scientifique des Aide-Mémoire). Gauthier-Villars, Paris, 1909. Paper, 2 francs 50; cloth, 3 francs.

Many of the methods of the analytical chemist employed in determining the identity of substances depend upon some physical property. Among those that have acquired extended application, the measurement of refraction indices, particularly in recent years, has proved of increasing importance. The literature on the subject has hitherto been available only in a somewhat fragmentary form, and it has been the author's aim to compile an account of the methods and apparatus employed for this purpose with an outline of the principles involved in the form—at once condensed and complete—characteristic of the Aide-Mémoire Series.

Something like a dozen different refractioners both for general and special purposes are thus described followed by numerous tables of refactive indices of a large number of solid, liquid, and gaseous substances. The volume terminates with a bibliography of the subject in the interests of investigators seeking a more detailed account of special apparatus. L. E. P.

SOUDURE AUTOGÈNE ET ALUMINOTHERMIE. Par E. Chatelain, Licencié ès sciences, Professeur aux Laboratoires Bourbouze, avec une préface par Henry Le Chatelier, Membre de l'Institut. x + 178 pages, 4½ x 7 inches, 48 figures. Paris, Gauthier-Villars, 1909. Price, paper, 3 francs 25.

Welding by means of the intensely high temperature flame of the oxy-acetylene torch has latterly found many industrial applications, and formerly unheard-of welding operations can now be performed.

The author, having under his direction a laboratory in which instruction in the various operations in soldering, brazing, and welding is conducted, is especially qualified to elucidate the subject.

The opening chapters are devoted to the allied processes of hard-soldering and brazing, after which comes a full and well-illustrated description of the torch-welding process using oxygen in conjunction with hydrogen, illuminating gas or acetylene. The final chapters treat of the now well-known processes of electrical welding and of the "Thermit" process, which latter is investigated at considerable length.

It is a timely and practical work.

L. E. P.

THE ELEMENTS OF MECHANICS OF MATERIALS. A Text for Students in Engineering Courses. By C. E. Houghton, A.B., M.M.E., Associate Professor of Mechanical Engineering in New York University. viii + 186 pages, 6 x 9 inches. D. Van Nostrand Company, New York, 1909. Price $2.00 net.

The mode of presentation of a subject in a modern technical course is rapidly becoming recognized as a problem of importance secondary only to the judicious selection of suitable subject matter. The author has doubtless been guided by this view in planning the present work. As he states, it is not a treatise but a text-book, compiled from the well-known work of Professor Merriman on the same subject and designed to meet the needs of students requiring a strictly utilitarian course divested of all non-essentials. Professor Merriman's order of presentation and notation are followed to facilitate reference to his treatise for a more elaborate discussion. The typography and cuts are attractively executed and the work is made of particular value as a drill book by the addition of a large and well-selected number of test-questions and examples distributed throughout the text.

L. E. P.

DIE STEINKOHLE, IHRE GEWINNUNG UND VERWERTUNG UNTER BESONDERER BERÜCKSICHTIGUNG DER NATIONALÖKONOMISCHEN BEDEUTUNG DER STEINKOHLE SOWIE DER NEUESTEN ANLAGEN ZU IHRER GEWINNUNG, UND VERWERTUNG FÜR PRAXIS UND SELBSTSTUDIUM ERLÄUTERT. Für Techniker Bergleute, Kohlenindustrielle und Kohlenhändler. Von A. Haenig. 329 pages, illustrations, plates, 12mo. (Band 82, Bibliothek der gesamten Technik.) Price in paper 5 marks Hanover, Dr. Max Jänecke, 1908.

A non-technical work on anthracite coal covering the entire subject. The geology and formation of coal is first considered, this is followed by a list of the more important European coal fields. Considerable space is devoted to mining operations—the shafts and their construction, timbering, blasts and blasting compounds, drilling and drills, the lighting and ventilation of mines, the dangers of fire-damp and mine gases.

The closing chapters of the work are devoted to the industrial uses of coal and include articles on the manufacture of coke, the briquetting of coal, coal markets and the statistics of coal.

R.

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